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ANALYSIS OF TRENCH DRAIN SYSTEMS BENEATH FOUNDATIONS

A Special Research Problem

Presented to

The Faculty of the School of Civil Engineering
Georgia Institute of Technology

by

Chris M. Willis

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GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
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In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Civil Engineering

Approved:

Dr. Richard D. Barksdale/Date 8/21/89

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Special gratitude is expressed to the U. S. Navy Civil Engineer Corps for sponsoring my studies and for the opportunity to attend this school.

Finally, I would like to express my special thanks to my wife, Pat and my sons for their patience, encouragement and support. Theirs is the support which makes everything possible and worthwhile.

ABSTRACT

This study is an analysis of the performance characteristics of a trench drain system used for foundation dewatering. By the uses of a finite element analysis program the trench drain system performance will be modeled.

Through the use of dimensional analysis techniques the results of the system modeling will be used to prepare a means of predicting the system performance for a wide range of variables.

As an economic concern the trench drain system will be compared with the common blanket drain. This comparison will provide information necessary for the selection of the method most economical for the application.

The trench drain characteristics of primary concern are the total system flow and the maximum free surface height of the water between trenches. The determination of the radius of drawdown for the system is a vital element of the prediction process and is a major portion of the study.

LIST OF FIGURES

CHAPTER 1

TRENCH DRAIN SYSTEM

I. Introduction:

Shallow foundations are susceptible to damage and leakage from the hydraulic forces of groundwater. The pressure of water will damage walls, pass into the structure through cracks and holes and contribute to the deterioration of metal, wood and concrete structural members. A structure will not satisfactorily full fill the intention of the owner if water gathers in the basement or garage of the building. A great deal of effort is expended by builders, owners and designers attempting to prevent water from infiltrating a foundation or collecting behind the walls. The most simple solution, as well as the most effective and economical is to properly design the foundation so that water is not present to penetrate the structure.

For a shallow foundation positioned at a moderate depth below a water table the foundation trench drain system is an alternative to expensive water resistent methods of construction. The foundation trench drain system is an application of a very old technique. A trench filled with highly permeable granular material collects water from surrounding, less permeable soil and carries it by gravity flow and slope to a sump or outfall,

where the water can be removed or wasted. Today the flow is usually in slotted pipes within the granular trench. Since the water can be removed from the highly permeable soil more quickly then it can exit the less permeable soil a difference in elevation of the water levels of the two soils is created. This gradient serves to provide continued flow as long as the gradient exists.

The gravity flow method is obviously very easy to implement and generally inexpensive. It does not always work well to dewater or drain a site sufficient to accomplish construction. It is usually not effective to attempt dewatering by gravity flow when (Powers, pg.236):

a. Soil is a loose granular deposit without plastic fines.

b. The soil has a high permeability.

c. There is a proximate source of large recharge to the water table such as a lake or river.

d. The aquifer is artesian or bounded under a positive head by an impermeable upper surface.

e. The depth to be dewatered is large so that there will be a high gradient between the water table and the base of the foundation.

If the soil to be dewatered does not have the limiting conditions gravity dewatering still might not be

advisable. The tendency of a soil to hold water is called storage. All soils will retain water by capillary tension while the apparent water table level is drawn down. A soil with a high storage have a surprisingly large amount of water held above the water free surface(Powers, pg.114). Removal of the held water may require energy in the form of pumping.

For this study the trench drain system for dewatering beneath a foundation will be evaluated. The evaluation will be done assuming that construction of the foundation is complete and construction dewatering has lowered the free water surface to below the design final elevation. The trench drain system will maintain the free water surface at the final elevation and not in contact with the foundation.

II. <u>Purpose of the Study:</u>

In this study the characteristics of a trench drain system will be evaluated with the use of the Aral Seepage Program, a finite element analysis program. Under a range of normal variables a trench drain system will be evaluated to determine; (a)the output flow of the system under the different configurations, (b)the range to which drawdown of the water table can be expected and (c)the maximum rise of the free water surface between the trenches.

The results of the finite element analysis will be grouped under dimensional analysis to provide a model for prediction of the characteristics. The predictive method will be effective within the range of variables considered.

Finally a cost analysis of the trench drain system as compared to a blanket drain system. With this information a designer will be able to effectively select the most cost efficient solution to the problem considered if the choice is between the trench drain and the blanket drain system.

CHAPTER 2

PREPARATIONS FOR THE ANALYSIS

I. Introduction:

In preparation for collecting data to analyze the dewatering capacity of a trench drain system planning was necessary to facilitate the assimilation of results. Dimensional analysis, used in presenting the results of this study is briefly reviewed in this chapter.

As with all numeric seepage calculations the area to be dewatered is of critical importance. The size of the cone of depression or the radius of influence is the single most difficult parameter to establish. Many rules of thumb, observations and formulas exist from which the radius of influence is determined in practice. To predict the rate of flow and water table drawdown the radius of influence must be determined. The evaluation of the radius of influence for use with the Aral Seepage Program is reviewed in this chapter.

The Aral Seepage Program, a finite element analysis, used in evaluating the trench drain system of this study was detailed by an earlier study (Pirtle, Appendix A). In preparing for runs of this program several items were noted which amplify the instructions of the user's manual.

II. Dimensional Analysis:

In this study the modeling of a large trench drain system used, for dewatering beneath a foundation, was done using a finite element analysis program. There are an infinite number of geometries and conditions for such a system and it is not practical to run the program for each combination of dimensions and properties. The goal, to provide a detailed summary of the expected results for any single group of conditions from the results of a few models, requires a range of variables covering normal values. Results cannot be specific to a few configurations of the system.

Dimensional analysis is a systematic grouping of variables into a dimensionless product. The product can represent a very small model of the system or a full size application. The trends and results predicted from a collation of the dimensionless numbers will be true for any combination of variables. From a dimensionless number the quantity of flow or free surface elevation between trenches can be evaluated for an infinite number of conditions.

In arriving at the dimensionless numbers for use in evaluation, the variables must be identified and cataloged by dimensions (Langhaar, Chap 3). The variables are then grouped into dimensionless products. The results of this

study of trench drain systems is presented in terms of dimensionless products. From inspection and experimentation the dimensionless numbers which provide the most insight are used in evaluating the models.

The variables in the study of dewatering a foundation by use of trench drains are listed:

-radius of influence (L), units of length

-hydraulic conductivity, horizontal (k_h), units of length/time

-hydraulic conductivity, vertical (k_v), units of length/time

-trench spacing, (S), units of length

-trench width, (d), units of length

-free head above trench bottom, (h), units of length

-aquifer thickness, (h+H), units of length

-number of trench drains, (N), no units

-slope of aquifer, (p), no unit

For this study only four trench drains were considered so no range of variables will be available from which to reasonably predict the characteristics of systems with other then four drains. The affect of other than four drains will not be considered. With a dimensionless product, later studies may determine a correlation between a four trench system and other configurations.

The aquifer slope will often be zero or near zero. A multiple of zero will reduce any dimensionless number to zero so the slope will also not be used in the dimensional analysis. Slope is a critical variable and the influence of aquifer slope will be shown by individual results and trends. For intermediate results interpolation between of the considered slopes will be necessary.

The width of drainage trenches considered for this study was restricted to one value. The trench width varies in practice and a value of 1.5 feet provides the minimum space necessary for placement of drainage pipe and granular backfill. If it is more necessary to make the trenches wider, the amount of dewatering will increase (Pirtle, Chap 4) and there will be less hydraulic rise in the water table between trenches. A wider trench is a more conservative approach and the variable for width of trench drains is included as a dimensional consideration.

Hydraulic conductivities, vertical and horizontal, are the only variables with other then a length dimension. This complicated the forming of dimensionless products. The vertical and horizontal conductivities had to be in the product, which left five variables, all with a single length dimension. There are five combinations to form a dimensionless product, each with six alternative

arrangements. This study was done with the vertical conductivity (k_v) equal to the horizontal conductivity (k_h) so the combinations for experimentation are:

$$L,d,S,h \qquad L,d,S,(H+h) \qquad L,d,h,(H+h) \qquad (1)$$

$$L,S,h,(H+h) \qquad S,d,h,(H+h)$$

Each grouping has six different arrangements, yielding thirty possible dimensionless products. The results of the model runs were prepared in the dimensionless form. The products were compared and the arrangement which provided an insight into a relationship to total flow and the maximum free surface was selected for use. In this case the final product is:

$$Ld/h(h+H) \qquad (2)$$

The variable not included in the product was the trench spacing. In Chapter 4 trench spacing is considered in evaluating the total flow and the maximum free surface between trenches.

III. <u>Radius of Influence:</u>

The distance over which the water level is lowered by dewatering is commonly referred to as the radius of influence. The radius of influence is the distance from the point or line of water removal to a point where the water table is not affected by the dewatering operation.

Obviously any model of dewatering or pumping operations is dependent on the radius of influence.

The radius of influence can be accurately determined in the field by a pumping test. A pumping test, using a fully penetrating well in an unbounded aquifer not in contact with a body of water, will provide a measured output and drawdown at known radii. The drawdown when plotted against the log of time will allow for the calculation of the effective conductivity of the soil. Under the Dupuit assumptions mathematical models ((a)Powers, pg 100) can project a drawdown for various distances and pump outputs. Calculation of the radius of influence is also available with this method. For a trench drain system the pumping test method has several problems. The trench drain is a method of open pumping or gravity flow and will have a significantly lower output then would a pumped well. By its nature the trench drain system is longitudinally aligned and would not be modeled by a well with accuracy. The trench drain does not fully penetrate the aquifer and will offer a different output than a fully penetrating well (Leonards, pg 270).

It is not unusual for the radius of influence to vary greatly, often differing by an order of three to four magnitudes ((a)Powers, pg 108). The radius of influence is affected by every variable of the system. In general the radius will increase with time and as the drawdown is

increasing. For pervious soils the radius of influence is greater then for a soil of less hydraulic conductivity (Leonards, pg 261). In the evaluation of a trench drain system, after construction of the foundation, the dewatering has reached a steady state condition. The affects of time and initial drawdown will not be considered in this study.

Normally the radius of influence is selected based on knowledge of the area and experience with design of dewatering systems. Several formulas exist to calculate the radius of influence, usually considering the hydraulic conductivity, thickness of aquifer, free head above point of lowest drawdown and adjustment factors. Several formulas are listed below:

Means of Calculating the Radius of Influence

1. $Q = (.73+.27(H-h_0)/H)(kx/2L)(H^2-h^2)$

Gravity flow to a partially penetrating slot (Leonards, pg. 271) with Q=total flow, H=aquifer thickness, h_0=elevation of water in trench, x=length of trench, k= permeability and L=radius of influence. Use consistent units.

2. $L = 3.8h$

Highway subdrainage design (Moulton, pg 60) with h=drawdown in water level in feet, L=radius of influence in feet.

3. $R_o=3hk^{1/2}$

Radius of influence as a function of drawdown ((a)Powers, pg. 109 after Sichart) with R_o=radius of influence, h=drawdown. Use consistent units.

4. $Q/x = K(H^2-h^2)/L$

Water table flow from a line source to a drainage trench ((a)Powers, pg. 100). Q/x is the total flow per unit length of trench, k is permeability, H = thickness of aquifer, h= trench elevation, L = radius of influence. Use consistent units.

5. $G = S_y Lq/KH^2$

Predictive Analysis of Groundwater Inflows into Excavations (Freeze, pg. 494). G=a dimensionless discharge, S_y= specific yield, normally .01 to .3 (Freeze, pg. 61), K= hydraulic conductivity, H = aquifer thickness, q= rate of flow per unit length of trench, L= radius of influence. Use consistent units.

These formulas and others will predict a radius of influence for the characteristics of the problem. The prediction of a radius of influence for the foundation trench drain system is discussed in Chapter 4.

The radius of influence is an input value in the Aral Seepage Program. The program will calculate a quantity of flow and a water level free surface for a given radius of influence. The formulas from above and several others offer severe limitations to predicting the radius of influence. The formulas are not specifically for a trench drain system and to various degrees do not account for variations in horizontal and vertical permeability, partial penetration of the aquifer and gravity flow.

Water is produced from an unconfined aquifer by three mechanisms: (1) expansion of the water under reduced fluid pressures, (2) compaction of the aquifer under increased effective stress and (3) dewatering of the unconfined aquifer (Freeze, pg 324). In a gravity flow trench system water is not removed from the aquifer but, is carried away after it enters the trench (or leaves the aquifer). The water will leave the aquifer at a rate consistent with the Darcy principal, $Q = kiA$. Once steady state is attained the area, A becomes constant and so too is the flow. The amount of drawdown over the distance from trench to original water level (radius of influence) is the hydraulic gradient, i. The permeability is a property of the soil and is assumed to remain constant. The gradient in a steady state gravity flow system can only change with a rising (infiltration)

or lowering (depleted) water table. To change the gradient in a stationary water table an outside action must take place to change the fluid pressures or to physically remove water from the aquifer. Pumping would be a means of changing the gradient and hence the radius of influence and outflow of the system.

The theoretically correct radius of influence for ideal conditions was determined by running each trench drain configuration at a series of different radii. The resultant total flow of the system were plotted against the trial radii of influence. Total flow is the cumulative outflow from all four trenches. Figures 2-1 through 2-12 are the results of the runs. The above discussion shows the radius of influence to be at the distance where no further drawdown occurs. The trial radii greater then the true radius of influence yields a result at the true free surface. Lesser trial radii results in a forced solution with a larger gradient and higher flow. For this study the radius of influence was selected from the figures 2-1 through 2-12 as the distance where flow became constant.

Establishing the distance where total flow remained relatively constant required a uniform criterion to define unchanging flow. Arbitrarily, unchanging total flow was defined as 10% change over a 100 foot change in radius. This definition was selected after comparison of

the results across the thirty six different configurations of the problem as studied. For this problem, assuming a trench length of 200 feet the 10% change criterion is less then .05 gpm total flow.

The radius of influence is an extremely variable value, subject to interpretation and fine measurement. An accuracy of fifty feet was established as a reasonable estimation for the correct radius of influence.

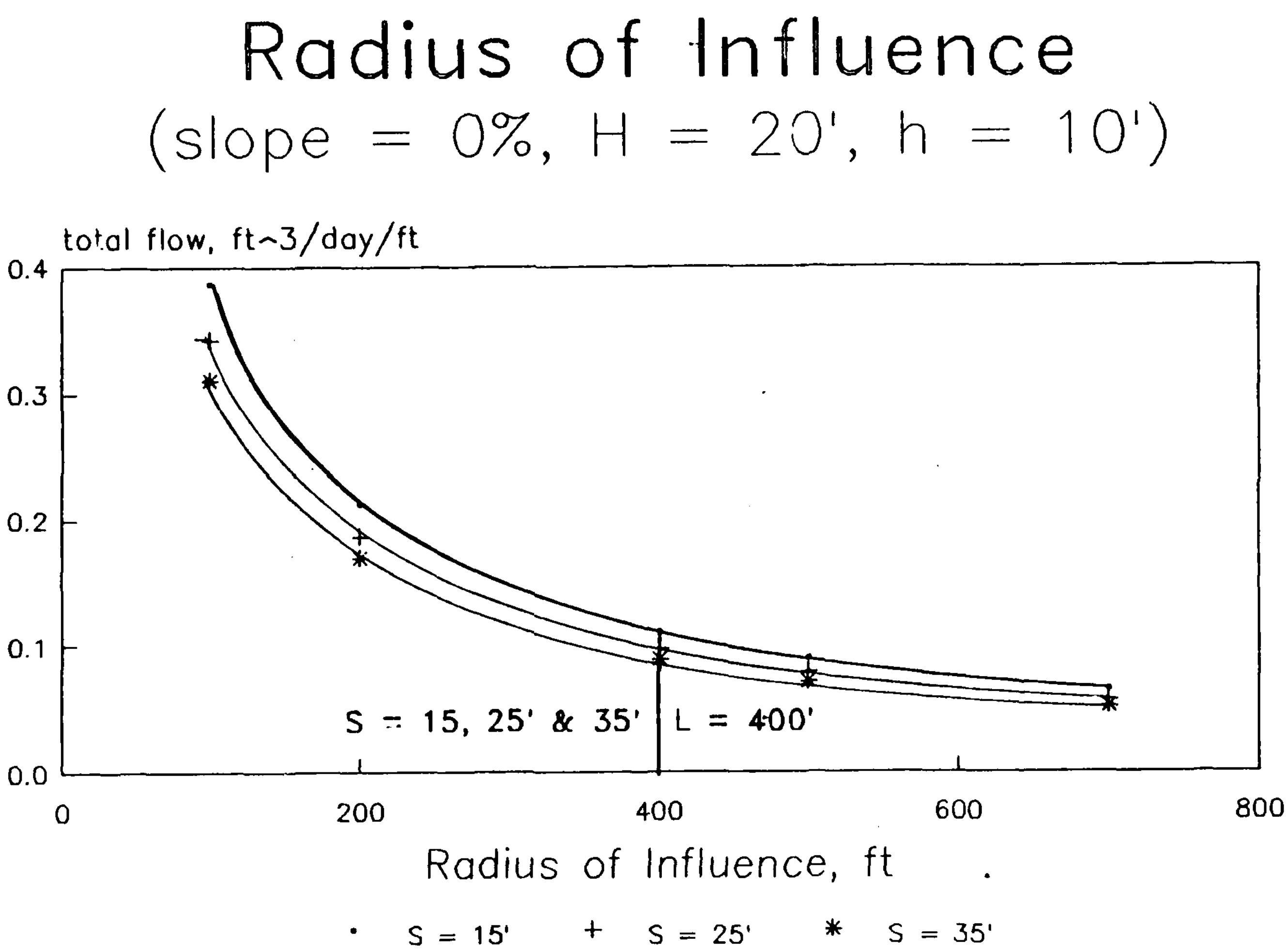

Fig. 2–1
Determination of radius of influence
S= Spacing, L= Radius of Influence

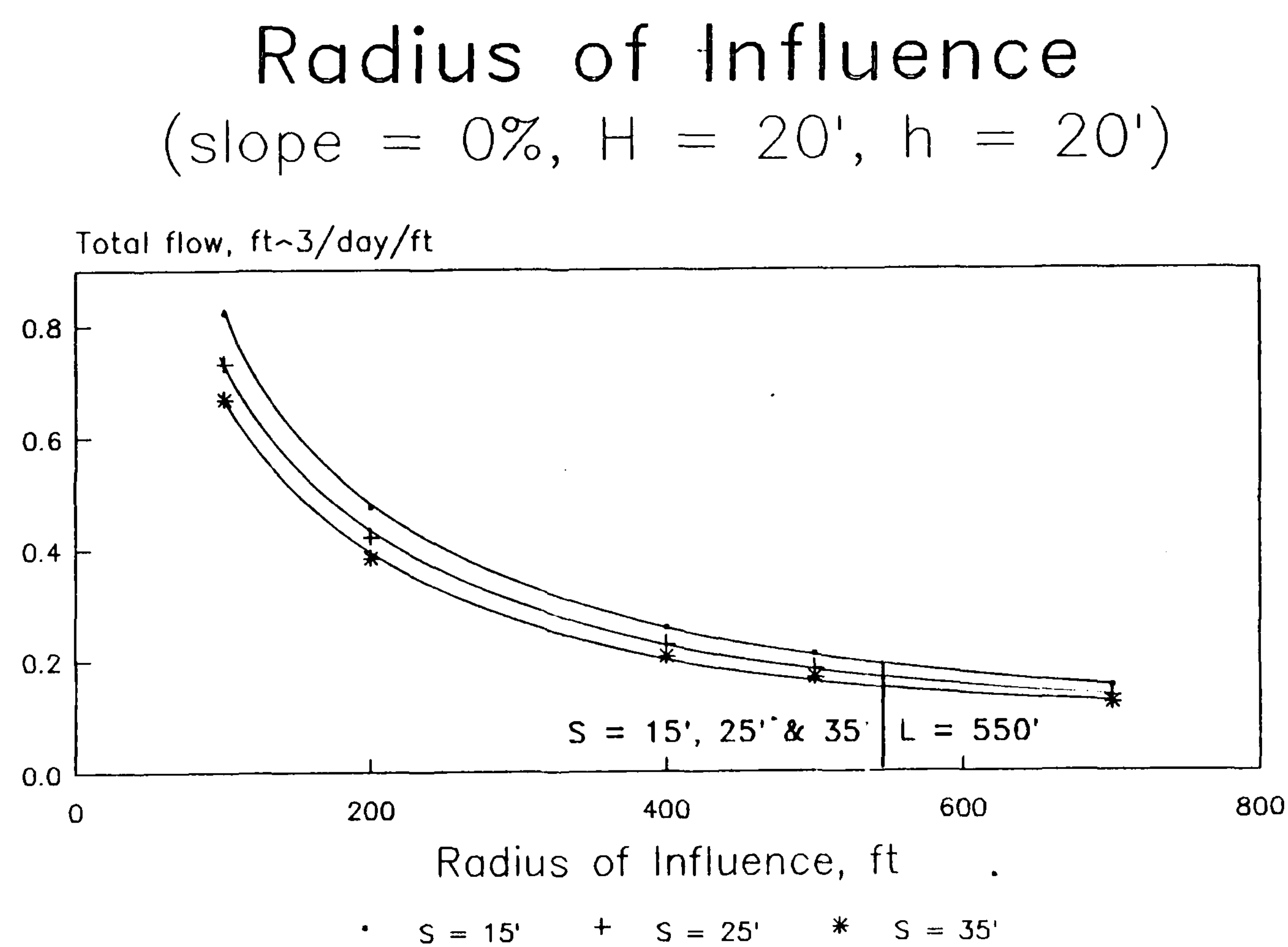

Fig. 2-2
Determination of radius of influence
S= Spacing, L= Radius of Influence

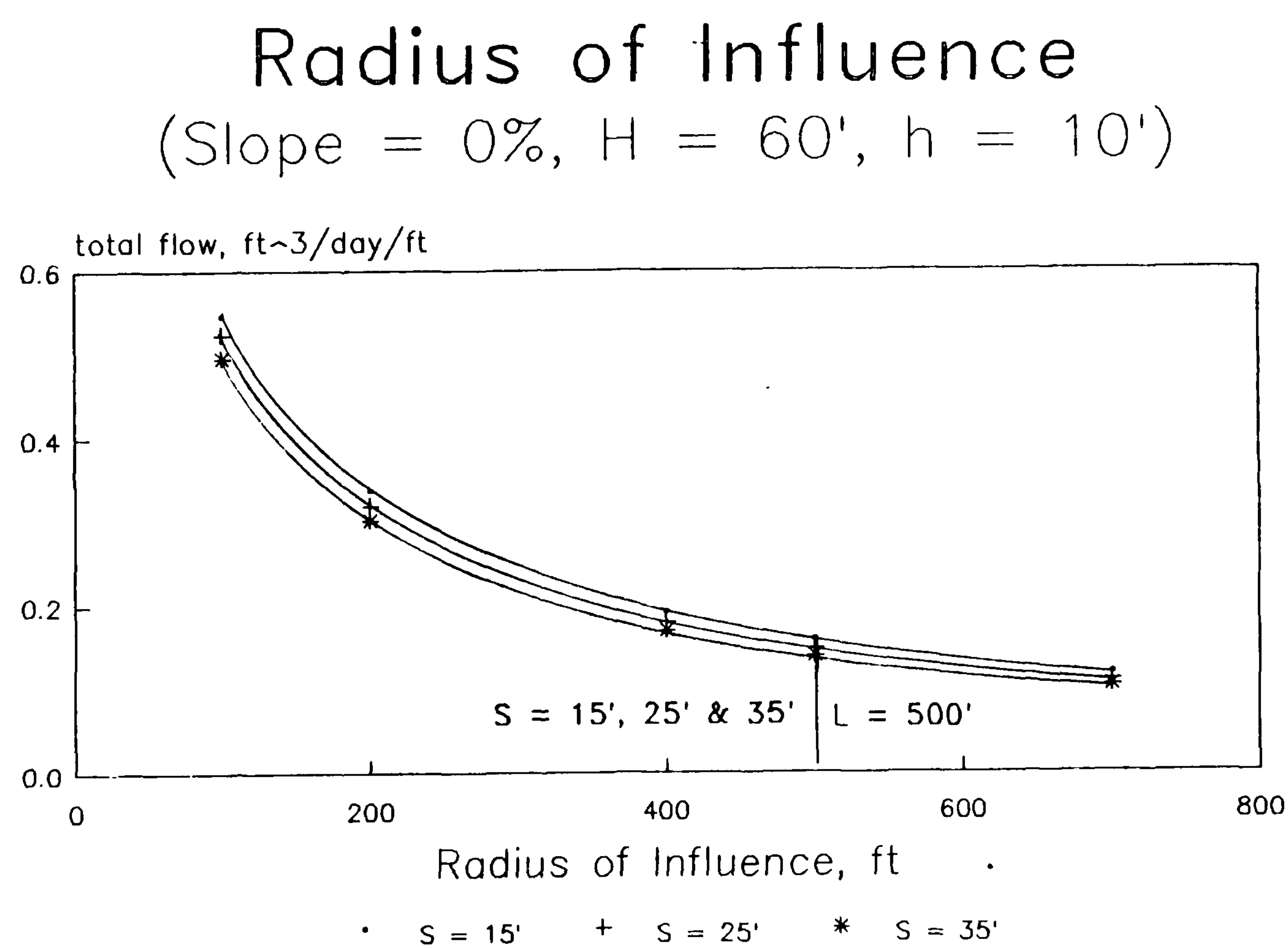

Fig. 2–3
Determination of radius of influence
S= Spacing, L= Radius of Influence

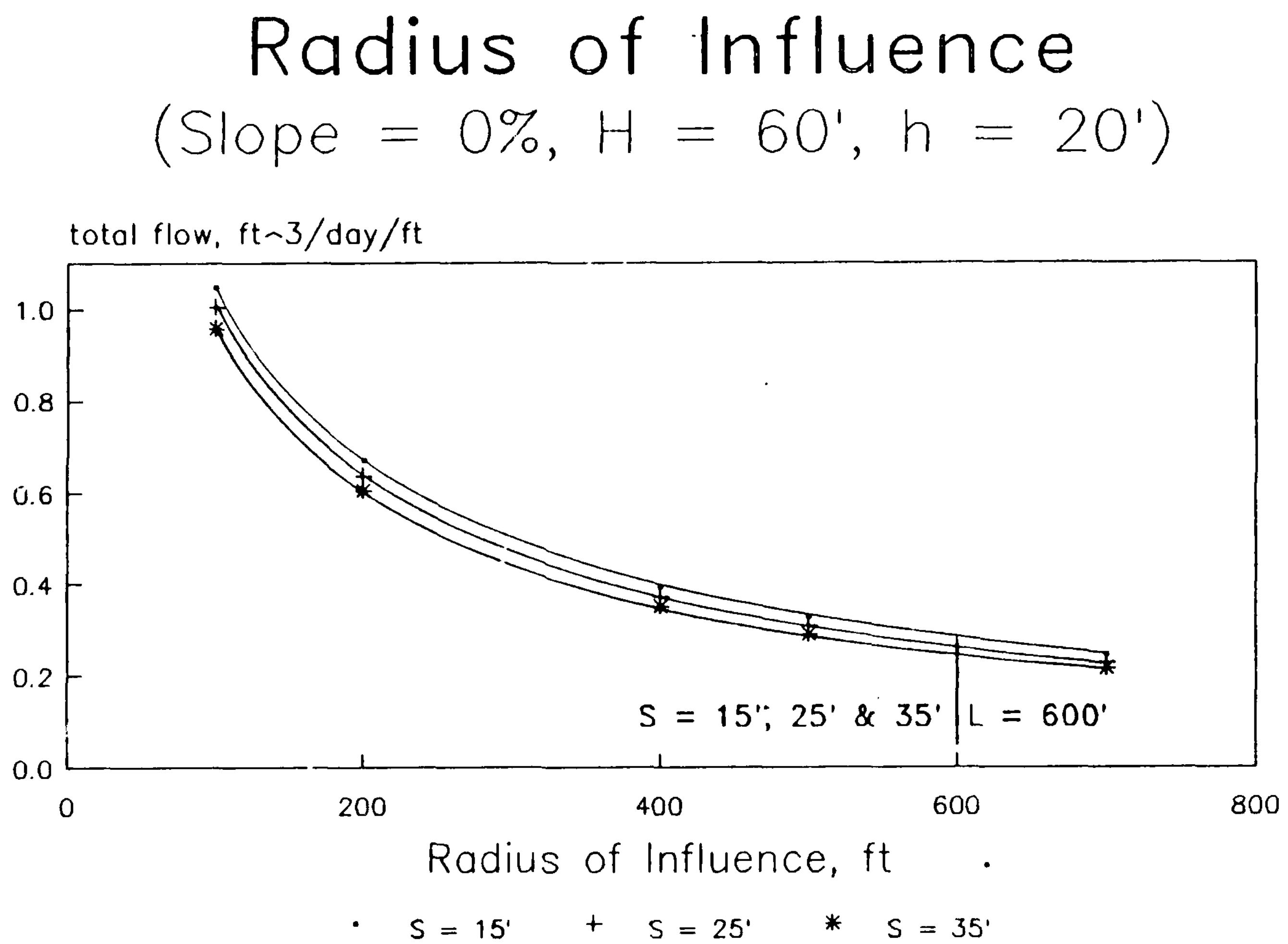

Fig. 2–4
Determination of radius of influence
S= Spacing, L= Radius of Influence

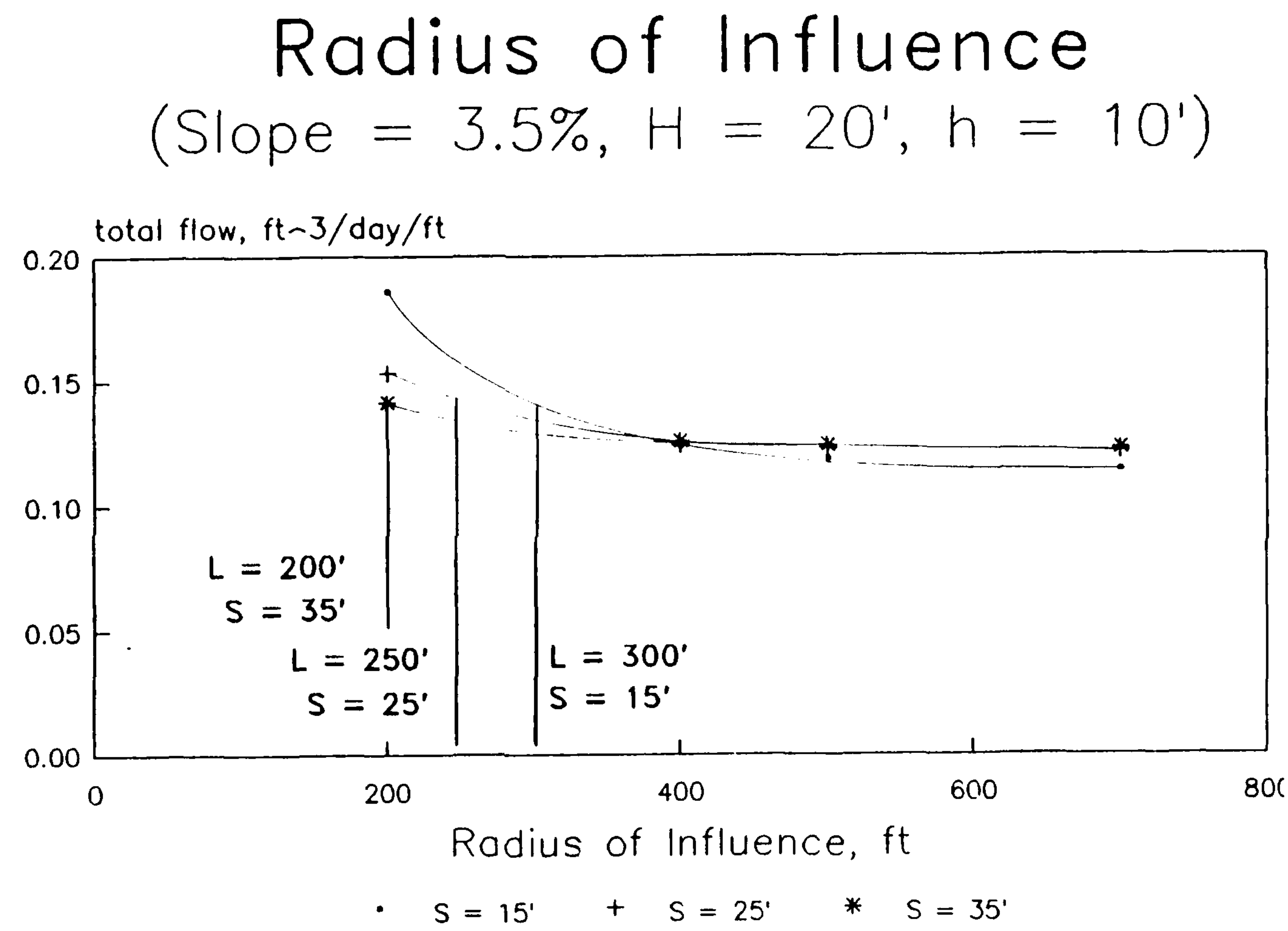

Fig. 2–5
Determination of radius of influence
S= Spacing, L= Radius of Influence

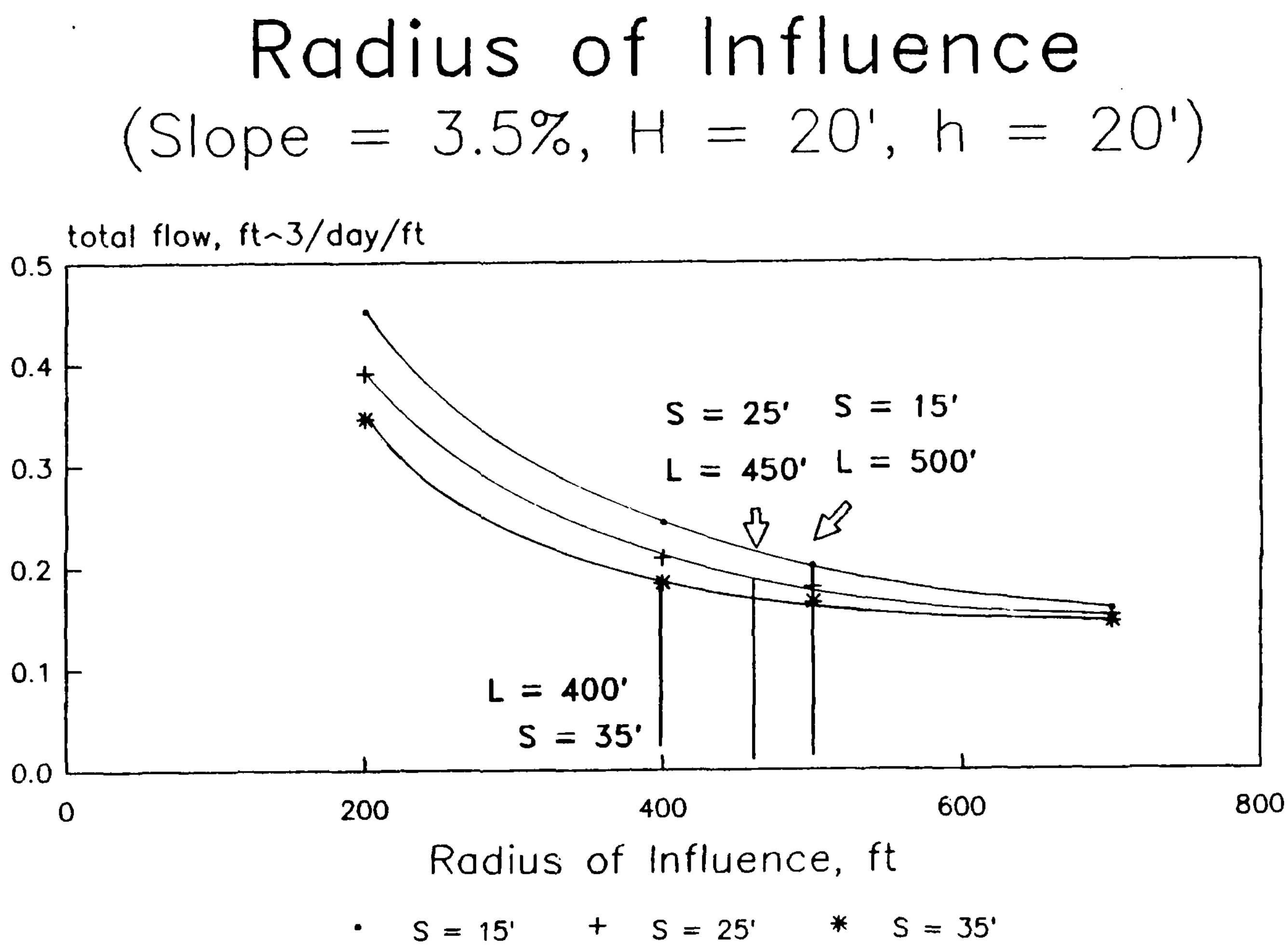

Fig. 2–6
Determination of radius of influence
S= Spacing, L= Radius of Influence

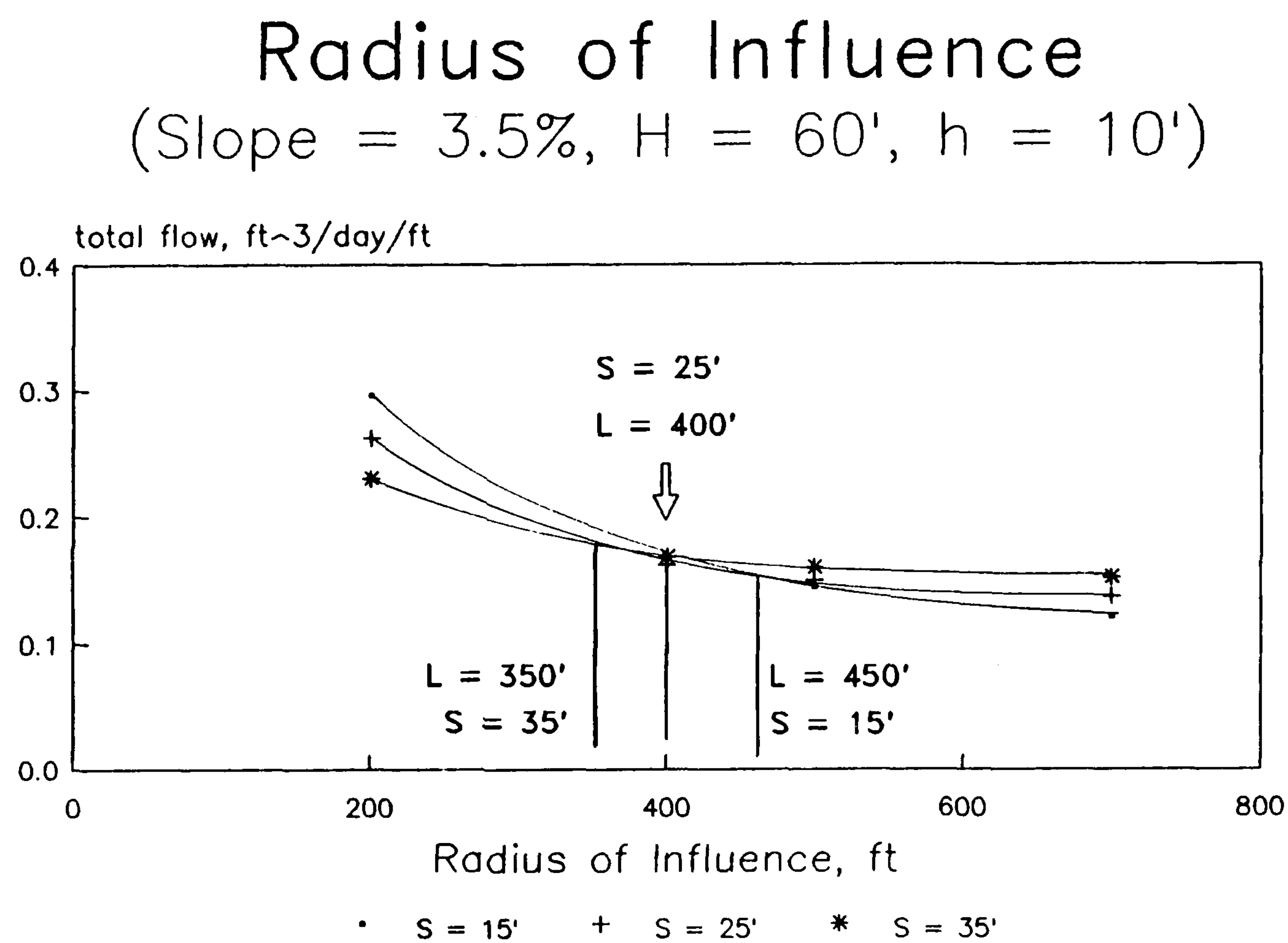

Fig. 2–7
Determination of radius of influence
S= Spacing, L= Radius of Influence

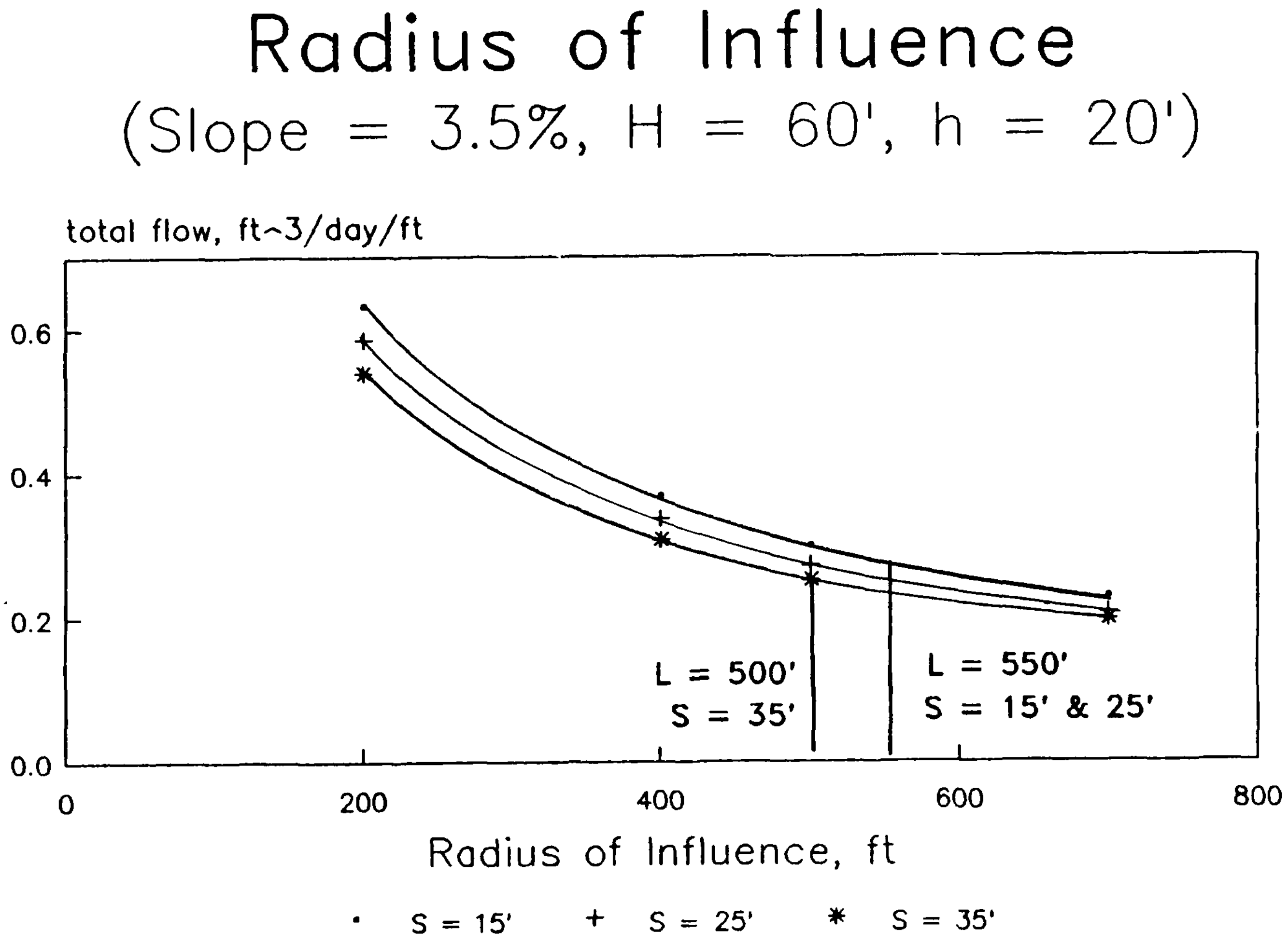

Fig. 2–8
Determination of radius of influence
S= Spacing, L= Radius of Influence

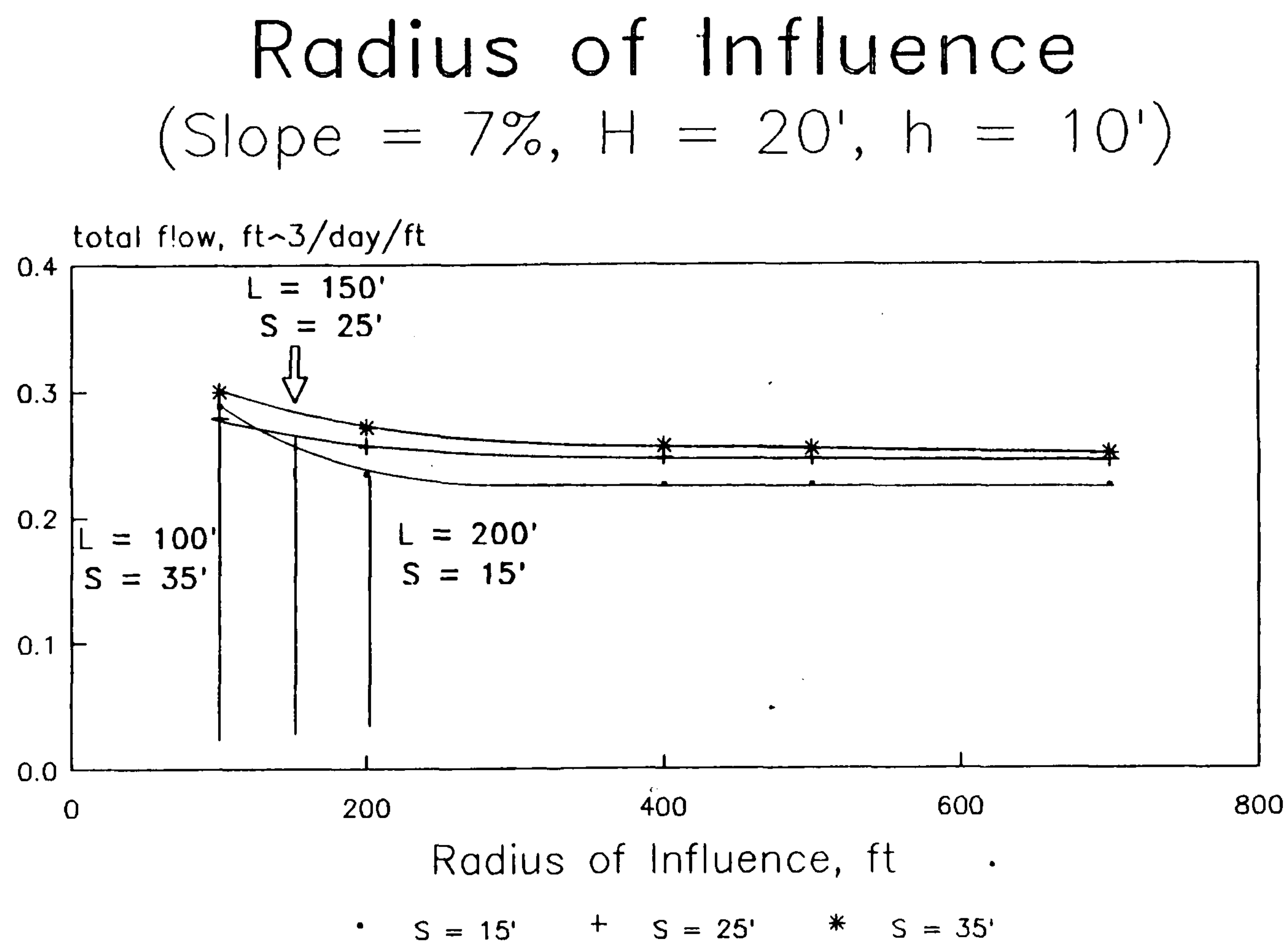

Fig. 2-9
Determination of radius of influence
S= Spacing, L= Radius of Influence

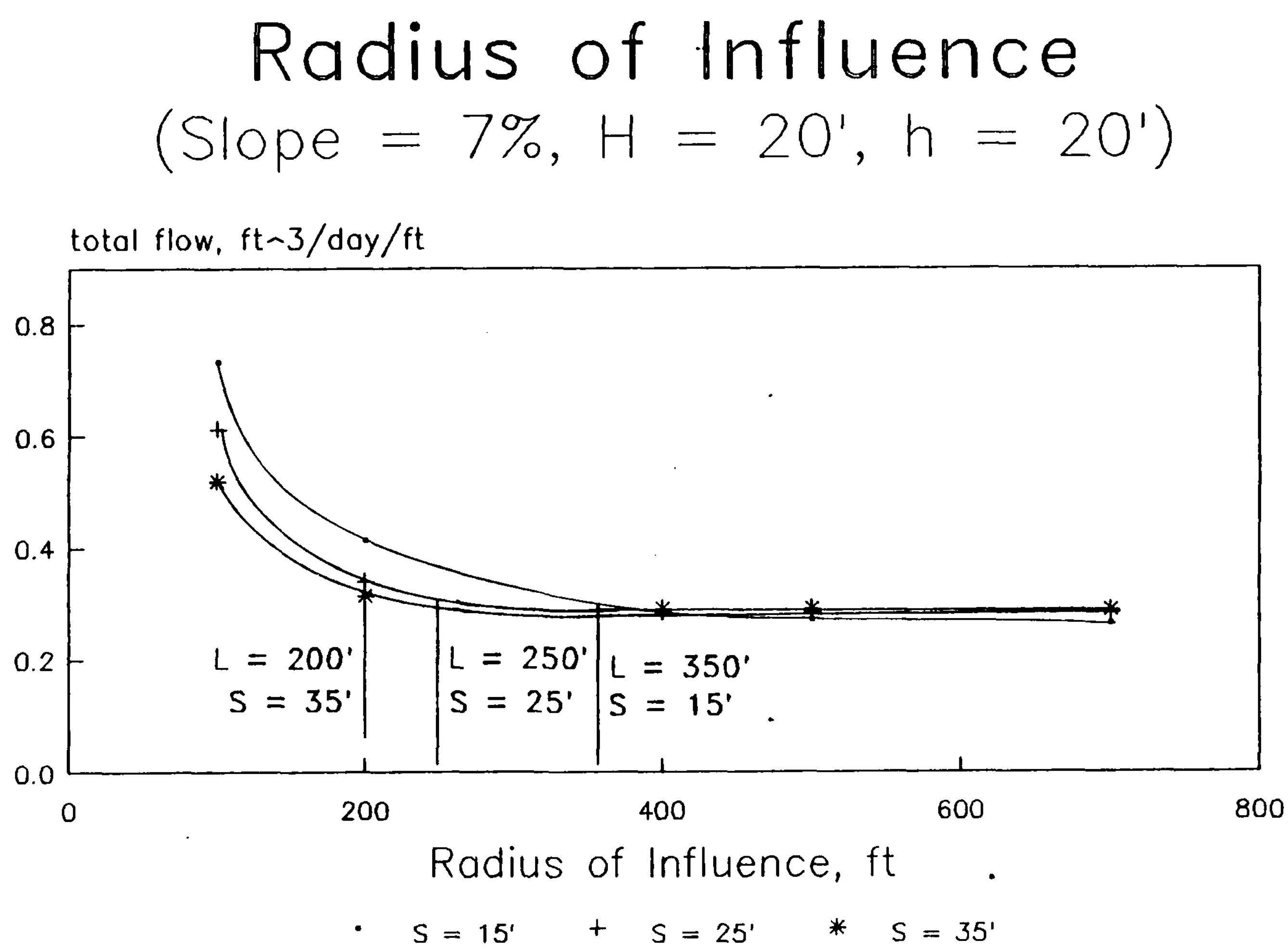

Fig. 2–10
Determination of radius of influence
S= Spacing, L= Radius of Influence

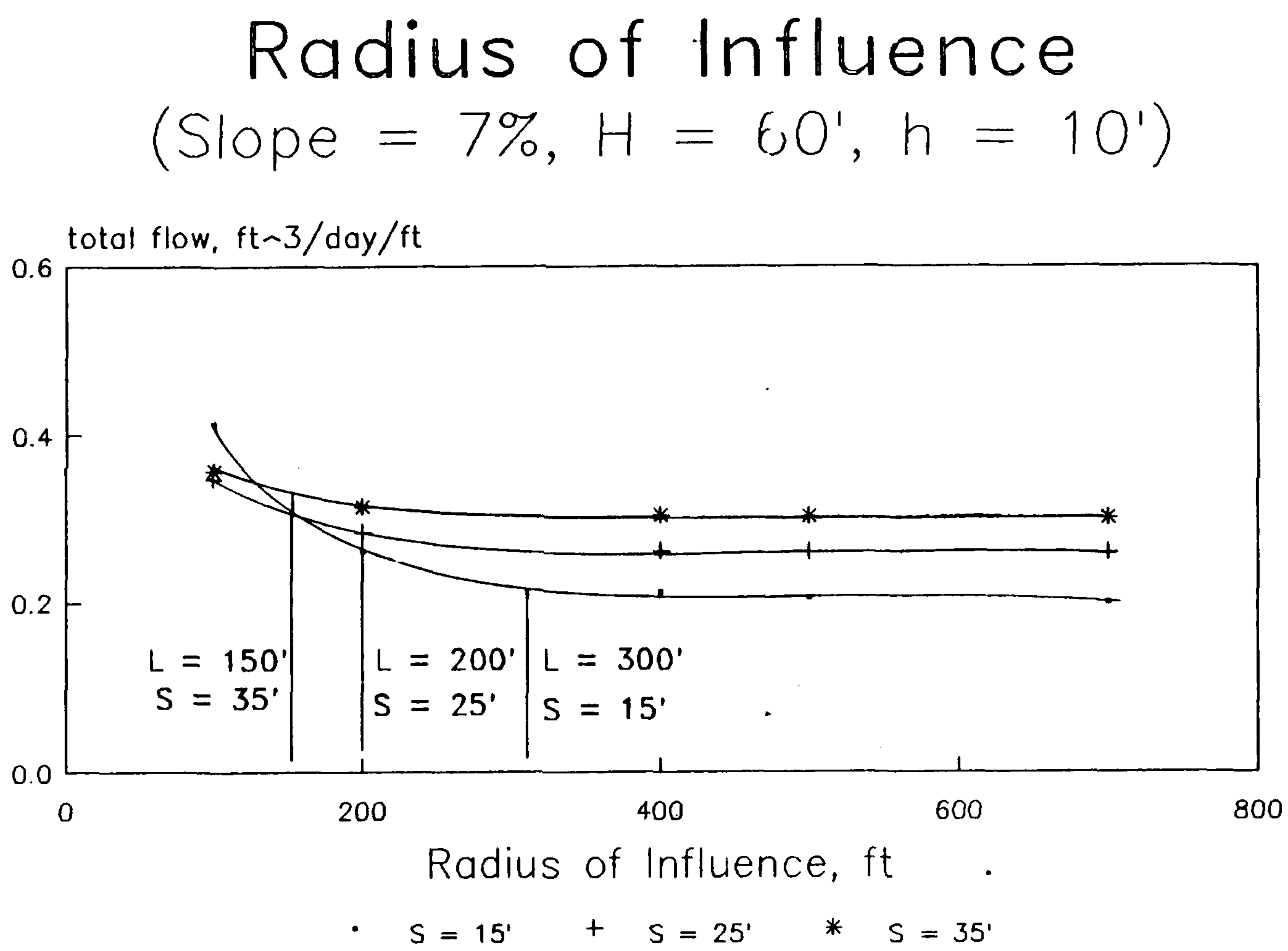

Fig. 2–11
Determination of radius of influence
S= Spacing, L= Radius of Influence

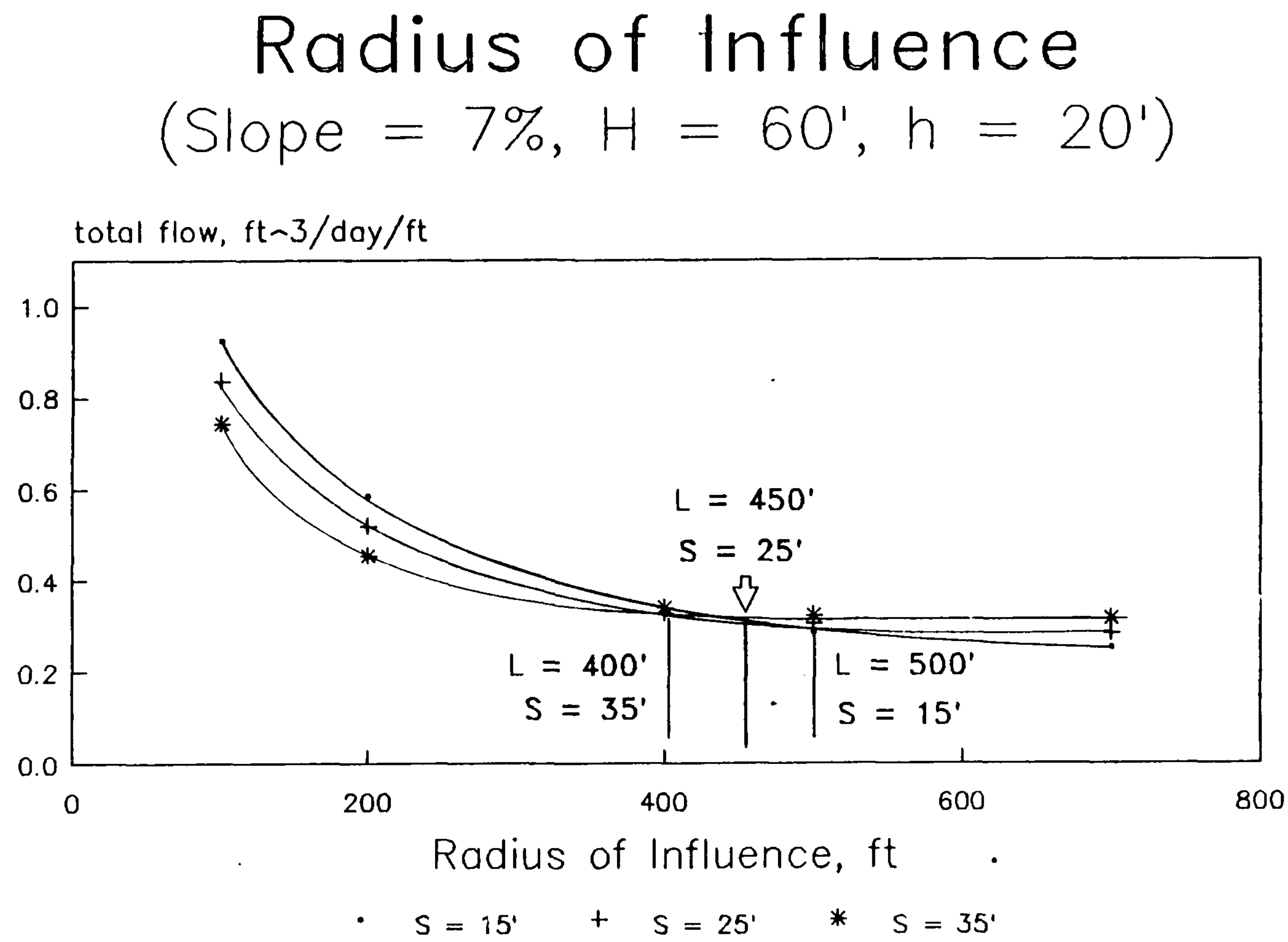

Fig. 2–12
Determination of radius of influence
S= Spacing, L= Radius of Influence

IV. Using Aral Seepage Program:

The Aral Seepage Program, a finite element model program was used in the evaluation of drainage characteristics of trench drain systems. An excellent program user's manual is included in an earlier study (Pirtle, Appendix A). Used for confined and unconfined flow problems of axisymetric or two dimensional seepage, the program is available at Georgia Institute of Technology, Department of Civil Engineering.

The user inputs the problem geometry, soil characteristics and position of ground water. By equilibrium solutions to the discrete grid elements the program adjusts the initially assumed free surface through several iterations until the level of accuracy is satisfied. When completed a solution is presented to the defined problem, including total seepage flow through seepage faces and the steady state free water surface.

The referenced user's manual includes detailed sample input for an unconfined seepage problem. The evaluated trench drain system is of the same nature and so input was extremely similar. Appendix B of this study is a copy of an input data file for a run of the Aral Seepage Program for a trench drain. Figure 3-5 of Chapter 3 will provide node and element numbers as used.

Comments on the Aral Seepage Program User's Manual:

1. The user's manual does not provide guidance in setting the model sensitivity on the Title and Type Problem Card (card FERR). This card sets the degree of accuracy which will discontinue iterations of the free surface calculations. A precise number is not as important as maintaining a minimum number of iterations during the run. Recommended accuracy will be a value such that a minimum of three iterations are completed in the free surface calculations. The necessary value of sensitivity will become evident after several runs.

2. The control card input for NNPC, total number of corner nodal points, makes it clear that intermediate nodes will be generated between the listed corner nodes. What is not clear is that it is recommended that a line of elements several rows below the free water surface, should be defined as corner nodes. This establishment of an unmoving row close to the free surface reduces the iteration time. Iterations occur between the intermediate nodes and the free water surface. Figure 3-5 is a sample of the finite element mesh used in this study.

The Free Surface Nodal Cards include the top and bottom corner nodes of the "movable zone" described above. Sixteen corner nodes, or eight sets of free surface and base, are allowed for each card.

3. General program notes not included in the user's manual:

-The current version of the Aral Seepage Program is limited to thirty columns of elements.

-The total number of seepage faces with Dirichlet boundaries is not necessarily one less then the total number of Dirichlet Boundary faces. In the trench drain problem six boundary faces exist with only four drainage faces. In a problem done by symmetry there would be one less seepage face then the number of Dirichlet boundaries.

4. The output from the Aral Seepage Program is extremely straight forward with only one area of confusion. Appendix B of this study includes a copy of a printout result from the study. Under the "New coordinates of the Free Surface Line" there are several iterations of free surface corner nodal points and the x and y coordinates. The last iteration is the free surface calculated within the desired accuracy. A plot of the listed x and y coordinates is a cross section of the free water level. The maximum free surface elevation between trenches is the maximum value between any of the four trench drains. In Chapter 3 the selection of this value is reviewed. The last page of the output contains

the total seepage flow. The area of confusion comes from the presence of seepage output between trenches, across element faces not defined as seepage faces. Those output figures are not correct. Using the nodal address numbers from the bottom of the trench (Fig. 3-5) the actual seepage output at each trench can be obtained. To find the total flow the sum of trench flows is calculated manually as the listed total flow reflects the imaginary outflow between trench faces.

V. Evaluation:

In the analysis of the trench drain system dimensionless products will be used to prepare presentations of the affect of the many changing variables upon which the solution is dependent. The key variable is the radius of influence which will be determined by solving each model for several different radii and selecting the correct value by interpolation. Finally in the future use of the Aral Seepage Program several notes can be used to augment the existing user's manual.

CHAPTER 3

INPUT AND OUTPUT OF THE TRENCH DRAIN EVALUATION

I. Introduction:

The evaluation of different variables in a foundation trench drain involves a significant amount of input and output data. It is extremely important that methodical presentation and collection of data be practiced. This chapter details the system, under which all variables were considered. The approach used insured that the entire range under consideration was evaluated.

II. Problem Geometry:

In evaluating the dewatering trench drain systems the geometry must established. Among the many variables in such an evaluation are the vertical and horizontal hydraulic conductivities of the soil, number of trenches in the system and width of the trench. To simplify the problem the above variables were held constant in this study.

Other variables in an evaluation are spacing between drains, thickness of the aquifer, free head above drains and slope of the aquifer. These factors were varied in this study over ranges sufficient to determine the characteristics of the system under as normally used.

Confined flow was not considered in this study and each case was for a water table aquifer. A confined aquifer cannot be dewatered effectively with an open pumping or sump method

((a)Powers, pg 114). A significant assumption of phraetic flow, included in the finite element analysis, provides the radius of influence of drawdown.

A primary concern in dewatering a water table aquifer is the storage depletion ((c)Powers, pg.3). This study concerns trench drains under steady state conditions following construction. In steady state, the storage has been depleted and will not contribute additional flow.

The previous study (Pirtle) was conducted under symmetry as a half space problem with no slope. The finite element method in a half space works very well until a sloping aquifer is considered. Use of symmetry permits evaluating one half of the problem, doubling the results accurately models the full problem. To do this with a sloping aquifer models a perched water table. Figures 3-1 and 3-2 represents one half of a system under symmetry and a full system respectively.

For this study the affects of a sloping aquifer were essential, and a full width model was required. Figure 3-3 is a representation of the cross section of the sloping aquifer. In the full width model the free water surface both upstream and downstream of the foundation trench drain must be evaluated. Figure 3-4 is a cross section of the problem with the assigned variable names.

In the model four trench drains were selected. Although this models a relatively small foundation it should yield results which may be used conservatively for larger

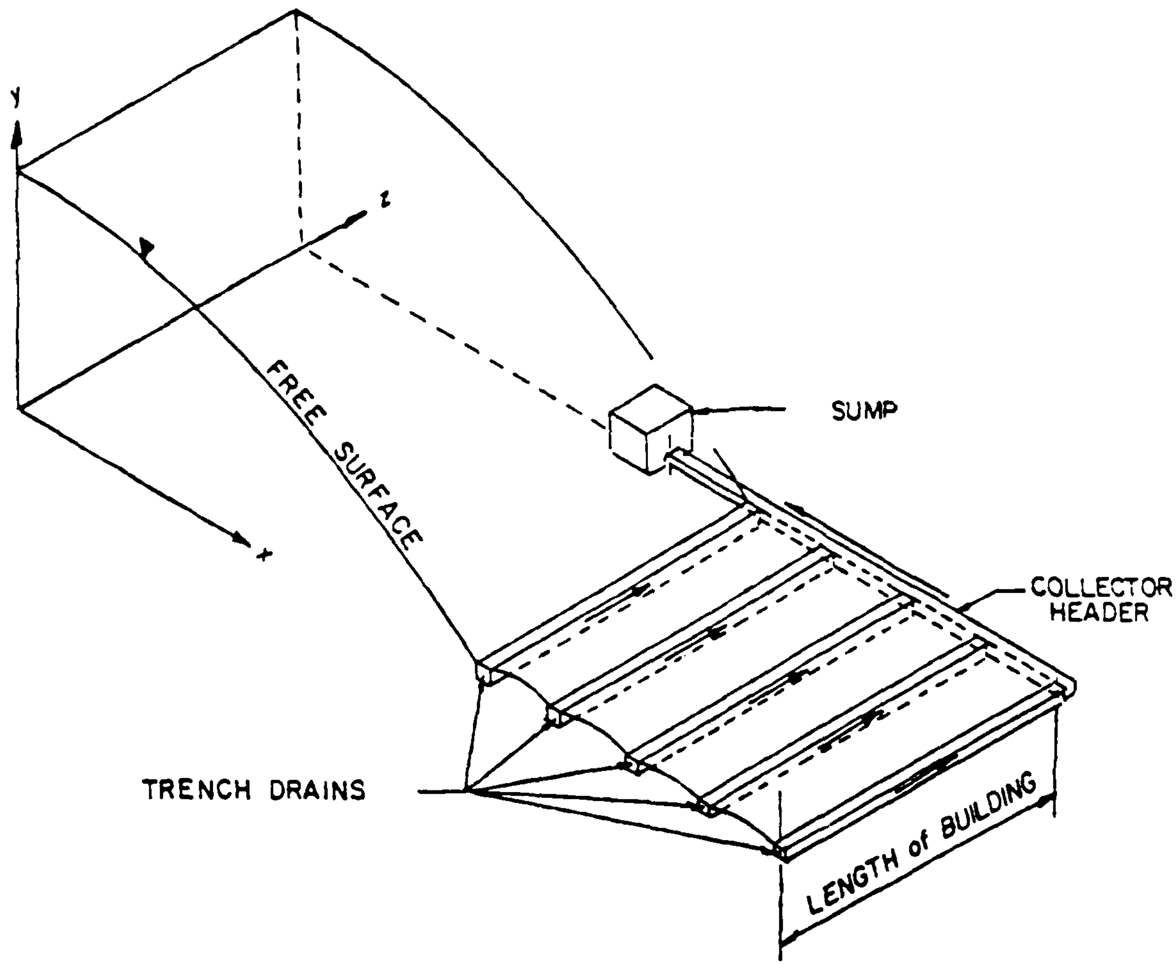

Fig. 3-1 Underdrain System in Half Space (after Pirtle)

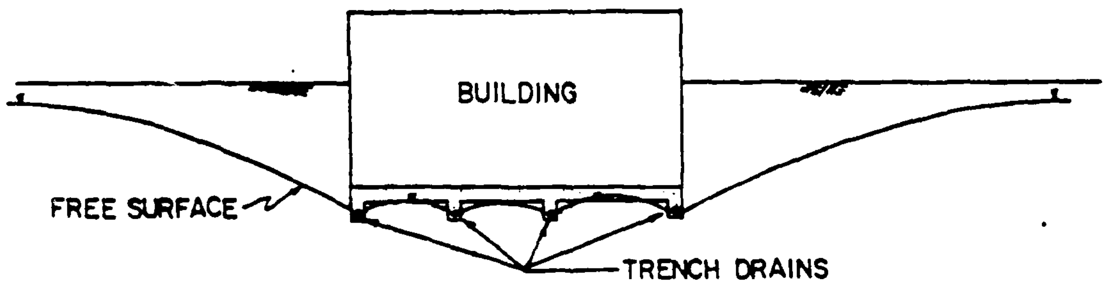

Fig. 3-2 Typical application of Trench Drain (after Pirtle)

TRENCH DRAIN SYSTEM

Profile

(L = 200', slope 3.5 %)

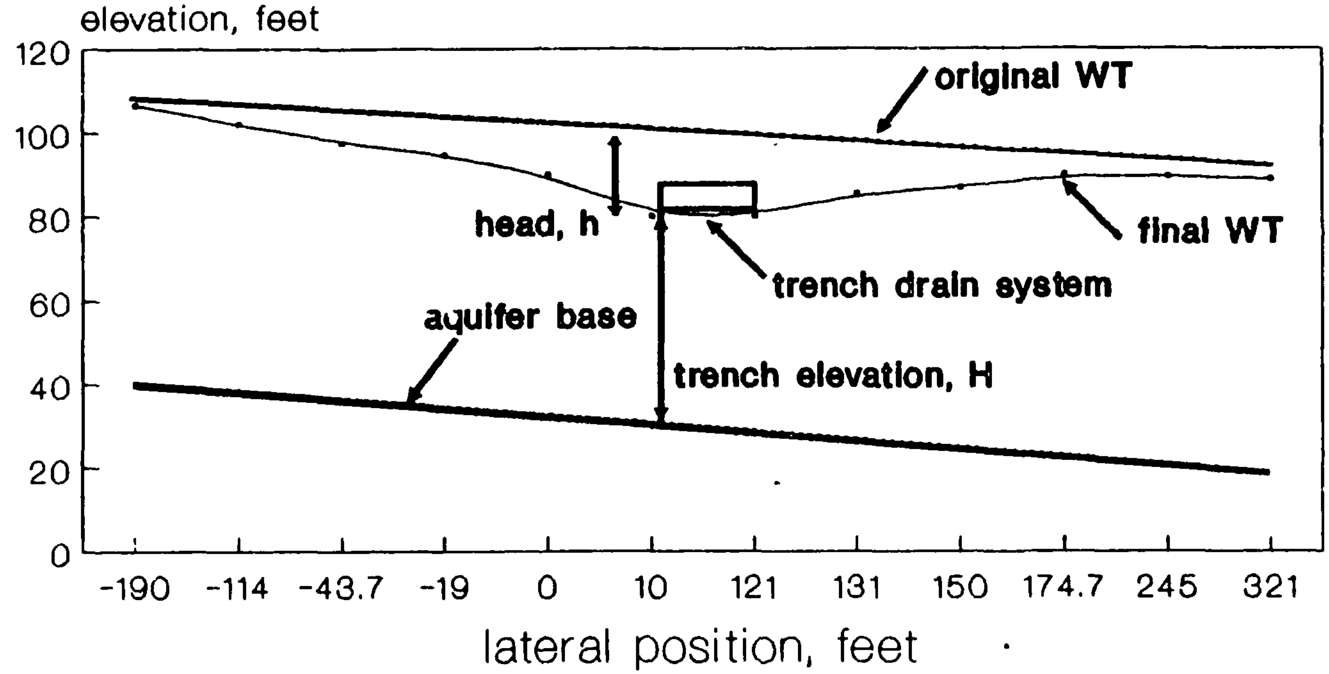

Fig. 3-3
Typical cross section of trench drain system with original aquifer boundaries

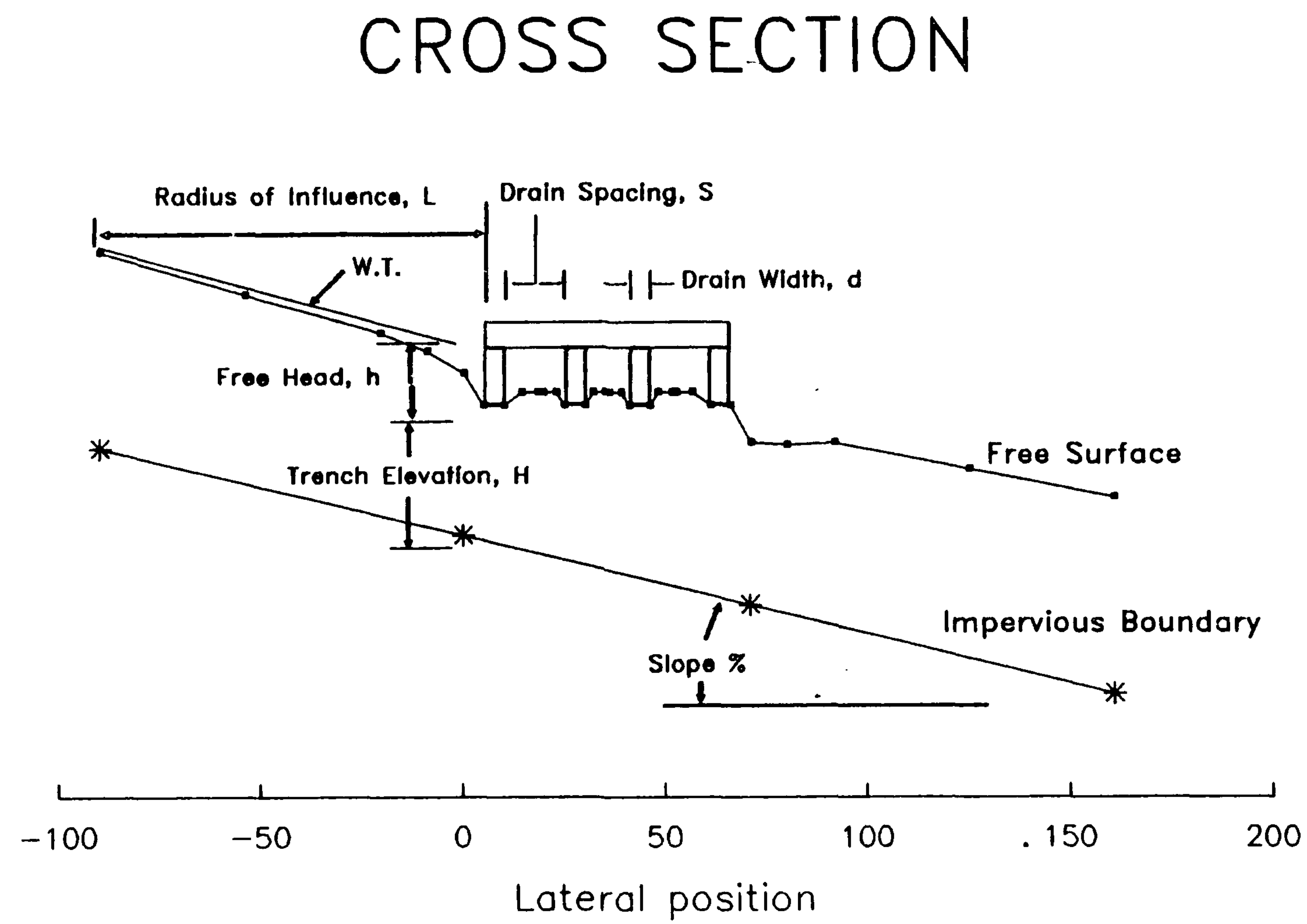

Fig. 3-4
Variables of Trench Drain Analysis

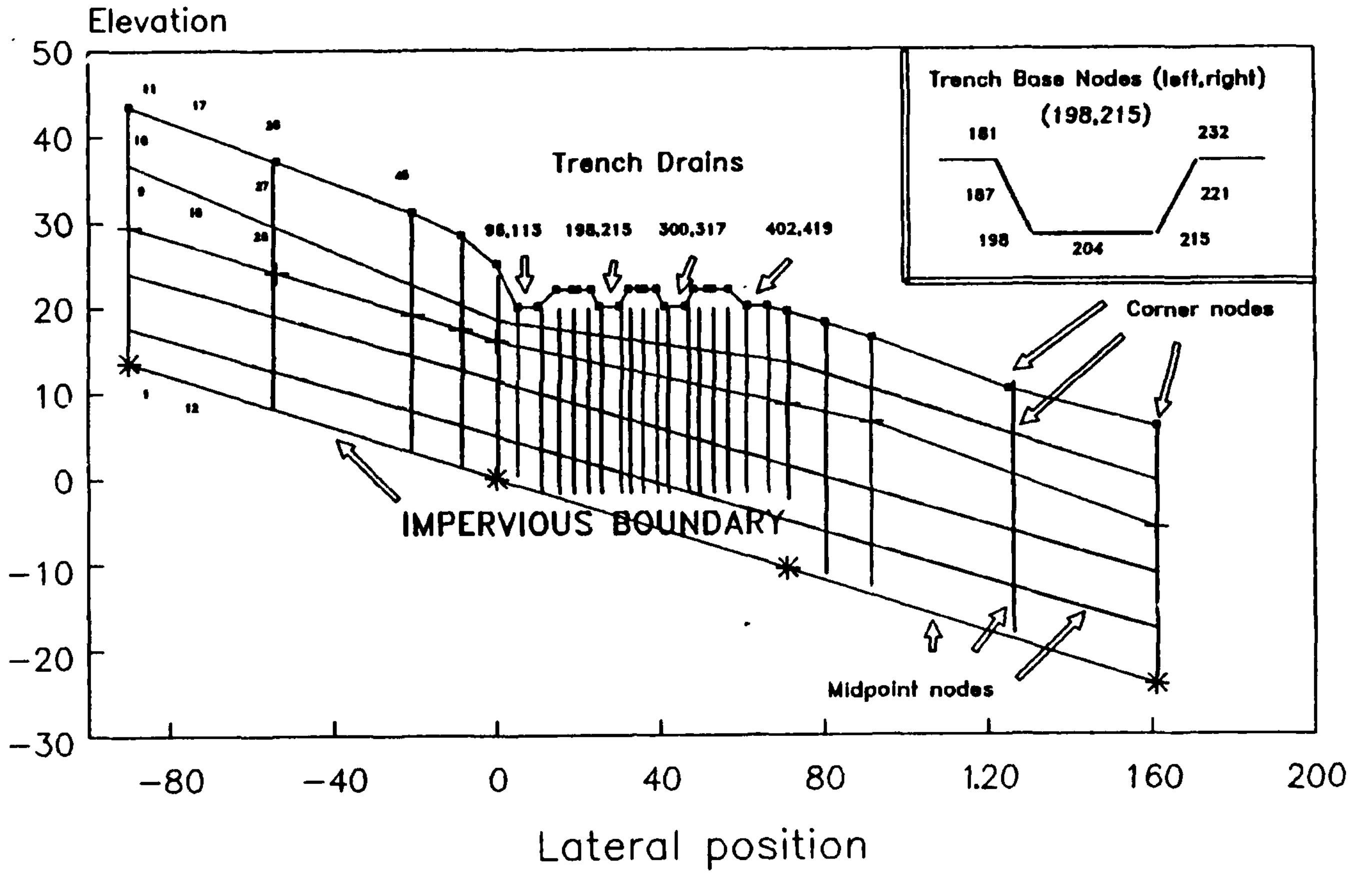

Fig. 3–5
Example Mesh Used

foundations. Generally in a sloping aquifer the majority of dewatering and the maximum free surface between trenches occur due to the outboard drain. For a sloping aquifer this model will closely model even a large foundation as most of the removed water is into the upstream trench. The number of drains might be a prime area for future study.

The width of the drainage trenches were held at one and one half feet wide. While the earlier study (Pirtle, Chap 4) showed total flow to vary with drain width, it is reasonable to select a single, typical value. The use of 1.5 feet is based on the approximate width of a normal backhoe bucket.

The horizontal hydraulic conductivity (permeability, k_h) was selected as a constant 0.2 ft^2/day/ft which is, 7×10^{-5} cm/sec. This is the normal permeability of a silty sand ((b)Cedergren, pg 34), common to the Atlanta area.

For the vertical hydraulic conductivity (K_v) the same 0.2 ft^2/day/ft was used. While a reasonable value, it does not reflect the normal condition of a greater horizontal hydraulic conductivity, which may be greater than the vertical by a multiple of three to ten times ((a)Powers, pg.92). It would be an excellent study to evaluate the affects of anisotropy in the trench drain system.

The primary area of concern in this study were the affects of a sloping aquifer. To consider a complete range, three slopes considered. Initially 0%, 7% and 15% slopes were selected. The aquifer thickness remains the same through the

area of consideration with a uniform aquifer base and water table slope. Once the study was begun it became apparent that the 15% slope was too severe. The study was modified with 7% the maximum slope considered and additional data was collected for a 3.5% slope.

Trench drain spacing was evaluated using 15 feet, 25 feet and 35 feet. For the assumed four drain system this allows consideration of a foundation from 60 to 120 feet wide. In actual practice the trench drains are excavated between the column lines so normal spacing is that of the column spacing. The results for a model with trench spacing of 25 and 35 feet are most likely to be used.

An assumption for this study was that the aquifer remain of constant thickness across the entire area of water table depression. For some models this area is 1000 feet across. It is certainly not a normal soil condition for the aquifer to be so uniform. In general the area of depression is significantly smaller then the above value. Assuming uniform thickness for distances of 300 and 400 feet is reasonable.

To separate the affects of free head from thickness of aquifer the later was considered as two components. The first component was thickness below the drain or trench elevation (H) and the second was free head above drain (h). The sum of the two components is the total aquifer thickness.

To bracket normal conditions in the evaluation of trench drains a maximum aquifer thickness of 80 feet was used. While

arbitrary this value is reasonable in an aquifer at the surface. The minimum aquifer thickness used was 30 feet. Certainly smaller aquifers exist at the ground surface but, a trench drain would probably not be as effective as a cutoff wall in protecting the foundation for such a shallow depth.

The last variable considered in the study was the free head of aquifer above the bottom of the trench drain. As described above the free head is a component of the aquifer thickness. Free head was held at a maximum of 20 feet. As the free head increases the amount of water removed must also increase. Under an open draining trench system the radius of influence is much larger and interference with other structures is a problem. As a free head of 20 feet is approached alternative dewatering methods may have to be considered.

The minimum free head considered was ten feet. This value was selected arbitrarily. The foundation trench system would work very well for a smaller free head. In retrospect the minimum head considered should have been five feet. Less free head and the necessary trench depth would be so small that a blanket drain would be more economical. A comparison of the two drain systems will be undertaken on an economics basis in Chapter 4.

III. Naming and numbering convention:

As a shorthand means of identifying the variables (Figure 3-4) of this study each is named as follows:

Radius of influence, L

Total flow, q

Aquifer slope, p

Trench spacing, S

Trench elevation, H

Free head above trench, h

Maximum free surface height, F

Hydraulic conductivity (vertical), k_v

Hydraulic conductivity (horizontal), k_h

As described in Chapter 2 the determination of an accurate radius of influence involved four to six trial runs of a model. The result was 36 geometries and over 200 computer runs. In order to identify the geometry of each trial the data files and resultants were named from a file convention. An alpha-numeric name of six characters, with

each one have several values was used. The files were named and the data sorted as follows:

A12345.dat, where the .dat is a conventional suffix of the operating system

First Character (A)

Vertical hydraulic conductivity, k_v

A = 0.2 ft^2/day/ft

Second Character (1)

Aquifer slope, g

0 = 0 %

3 = 3.5 %

7 = 7 %

9 = 15 %

Third Character (2)

Radius of influence, L

3 = 100 ft

5 = 200 ft

8 = 400 ft

9 = 500 ft

0 = 700 ft

Fourth Character (3)

Trench spacing, S

3 = 15 ft

5 = 25 ft

7 = 35 ft

Fifth Character (4)

Trench elevation, H

2 = 20 ft

6 = 60 ft

Sixth Character (5)

Free head, h

1 = 10 ft

2 = 20 ft

The above convention is used in this study in names of data files. If a collection of data is gathered so that each group has a constant trench elevation, H and free head, h the data groups will be referenced by AxxxHh. In this example if the H = 20 feet and h = 10 feet the data group will be Axxx21. The data files used in this study are included in Appendix D.

IV. Conduct of study:

The primary output of the finite element analysis used in this study were the total drainage outfall per lineal foot of trench drain system and the maximum free surface of groundwater between trench drains. As detailed in Chapter 2 the study first had to determine the radius of influence for each condition. From Figure 3-5 the elements of the finite element grid between can be observed. The width between trenches was divided into five spans. So at four nodes the iterative determination of the FEA program predicted an

ultimate final elevation. This was determined for every trial radius, L and the maximum node elevation observed was recorded. Figures 3-6 through 3-9 are profiles, in the trench area, of the represented free surface for several trial runs.

It was expected that the maximum free surface (F) would occur near the center of the trench spacing (S). In order to obtain an accurate maximum free surface, the nodes between drains were not evenly spaced. Instead, the distance between nodes were greater near the trenches. For each run the maximum free surface selected was that of the maximum nodal elevation. This is obviously not accurate in all cases. An interpreted maximum free surface (F) would increase many of the values used but, would not reduce any value. The anticipated difference in magnitude of maximum free surface (F) does not exceed 0.01 feet or 0.1 inch. This potential error is not significant.

A review of the maximum free surface value for the many different finite element analysis runs revealed that the maximum free surface (F) always occurred between the outer most trench and the second trench. In an aquifer with no slope the conditions surrounding the outer trench were the same for both sides. On a sloping aquifer the maximum free surface (F) was at the upstream side of the trench drain system.

With the maximum free surface available for every geometry of problem and every trial radius of influence there

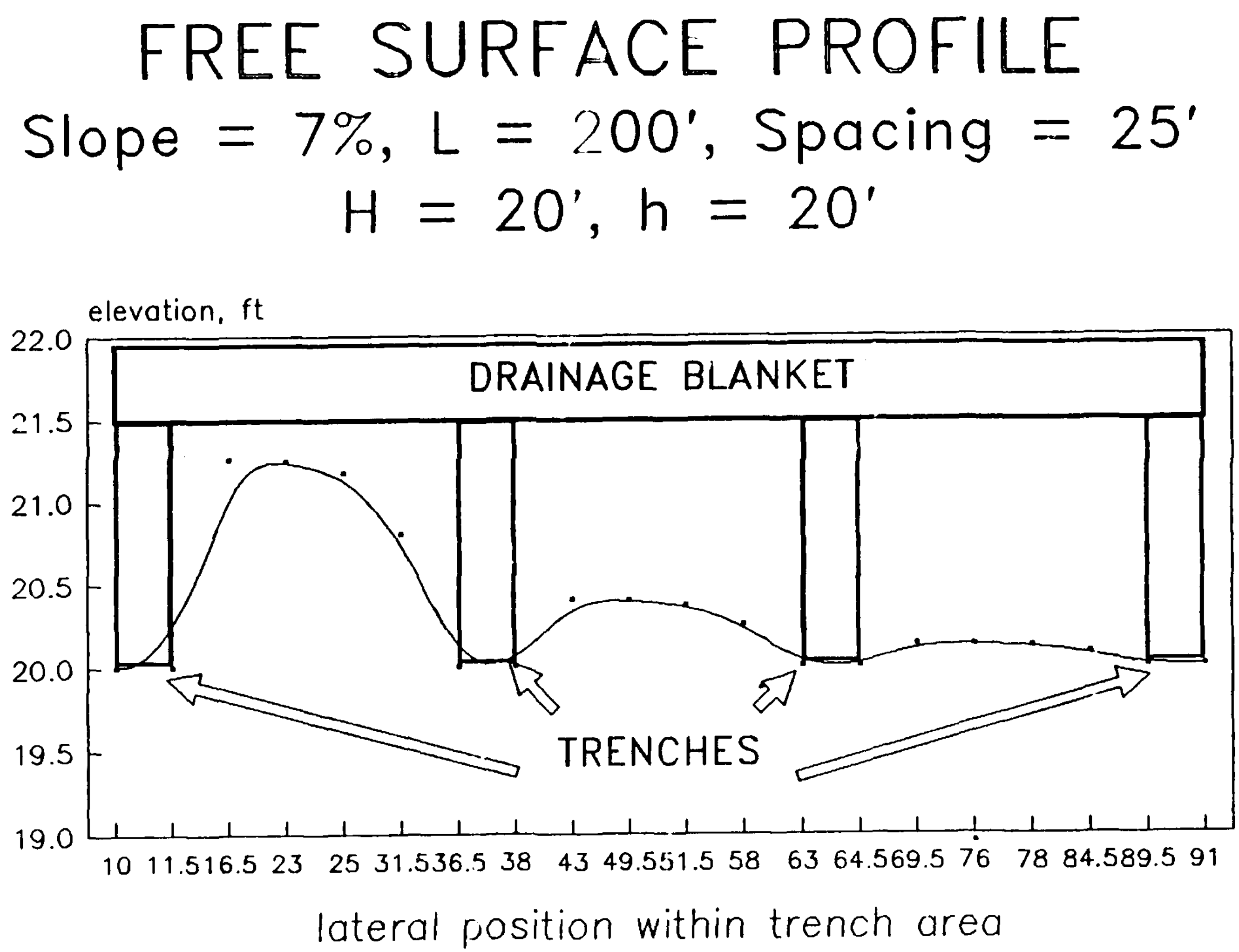

Fig. 3–6
Free surface between trenches

FREE SURFACE PROFILE

Slope = 3.5%, L = 700', Spacing = 25'

H = 60', h = 20'

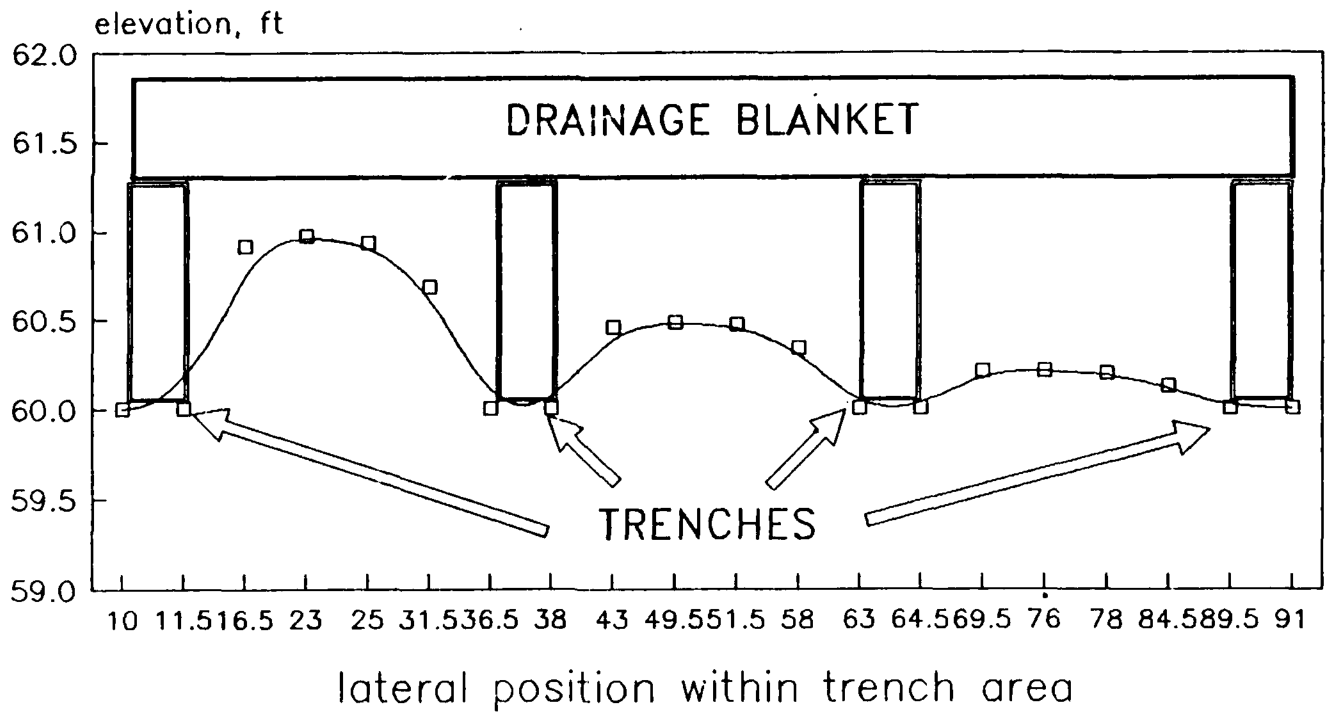

Fig. 3–7
Free surface between trenches

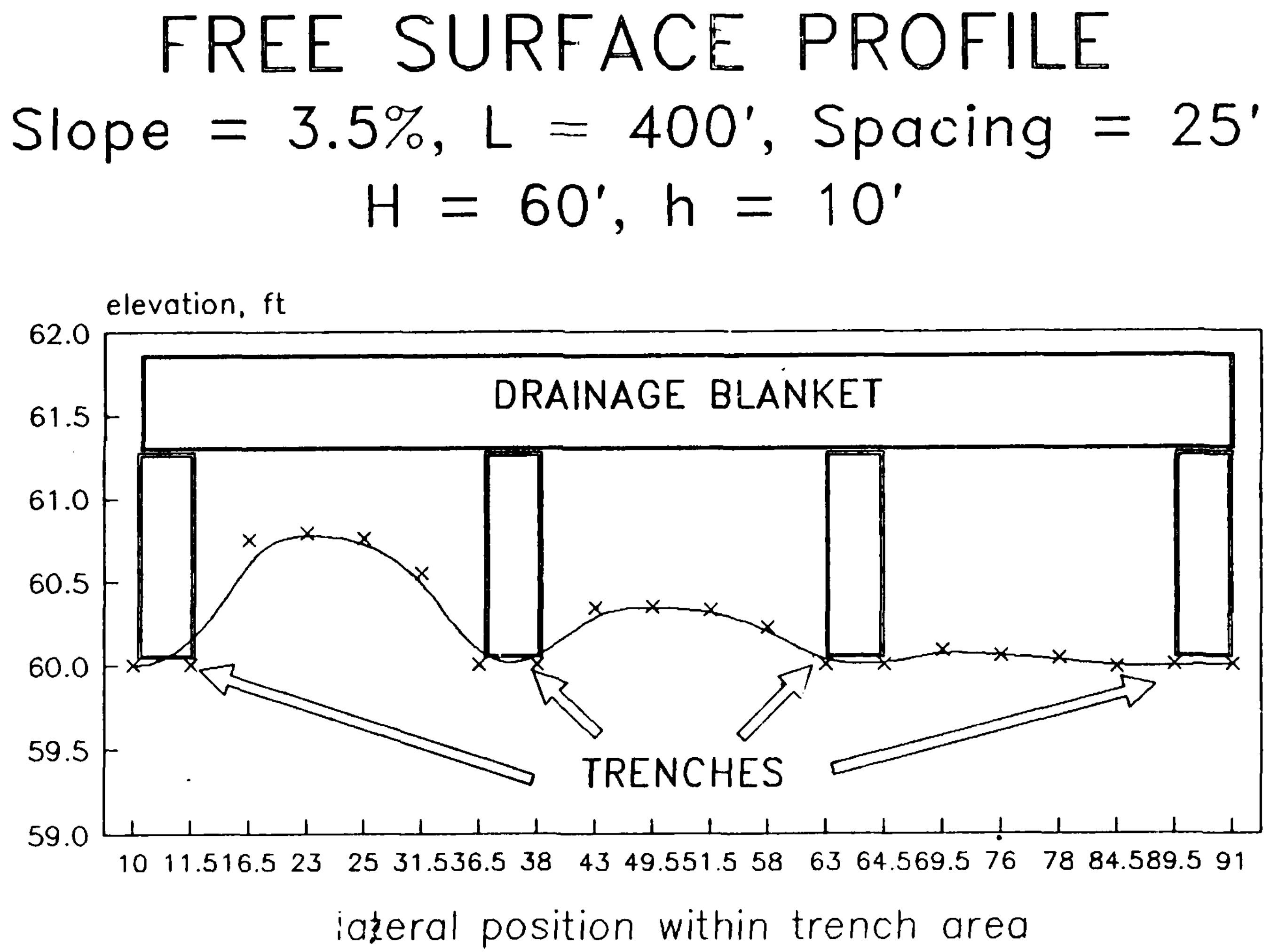

Fig. 3–8
Free surface between trenches

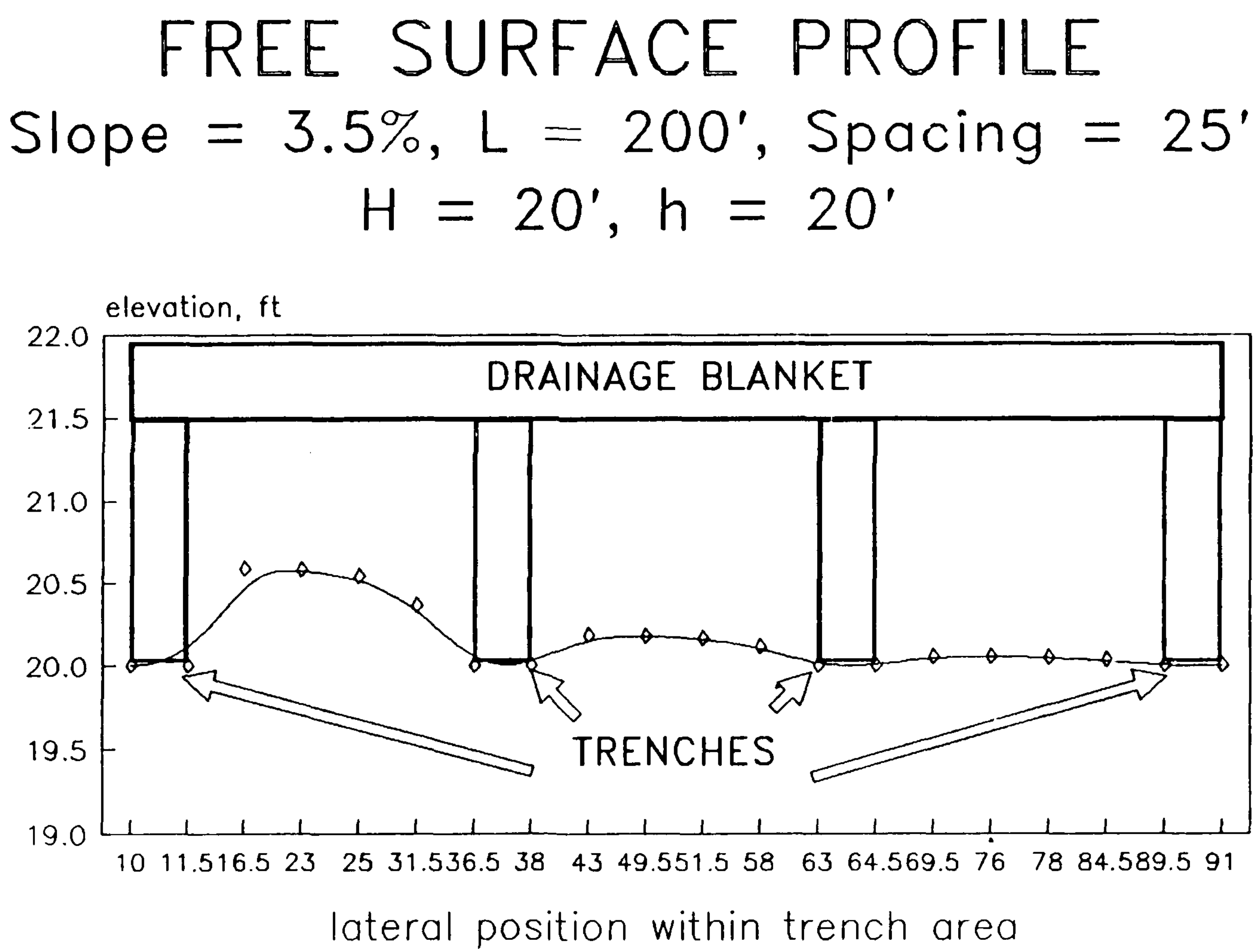

Fig. 3-9
Free surface between trenches

remained the evaluation of the maximum free surface (F) at the theoretically correct radius of influence. Fortunately from Figures 3-10 through 3-21 it is obvious that the maximum free surface varies with trial radius of influence in a consistent manner. As the theoretically correct radius of influence (L) is known from Chapter 2, the maximum free surface can be scaled from Figures 3-10 through 3-21. By convention the interpolation of data to evaluate the radius of influence used only values which were multiples of 50 feet.

The definition of a theoretically correct radius of influence at the distance of unchanging total flow defines the radius from the known phraetic nature of the problem. The unchanging flow also quantifies the total flow expected from the system. For this problem total flow was done per unit of width, making this a two dimensional problem.

The total flow, the maximum free surface and the radius of influence for each geometry of problem are now available. Analysis of trench drain systems were done with this data.

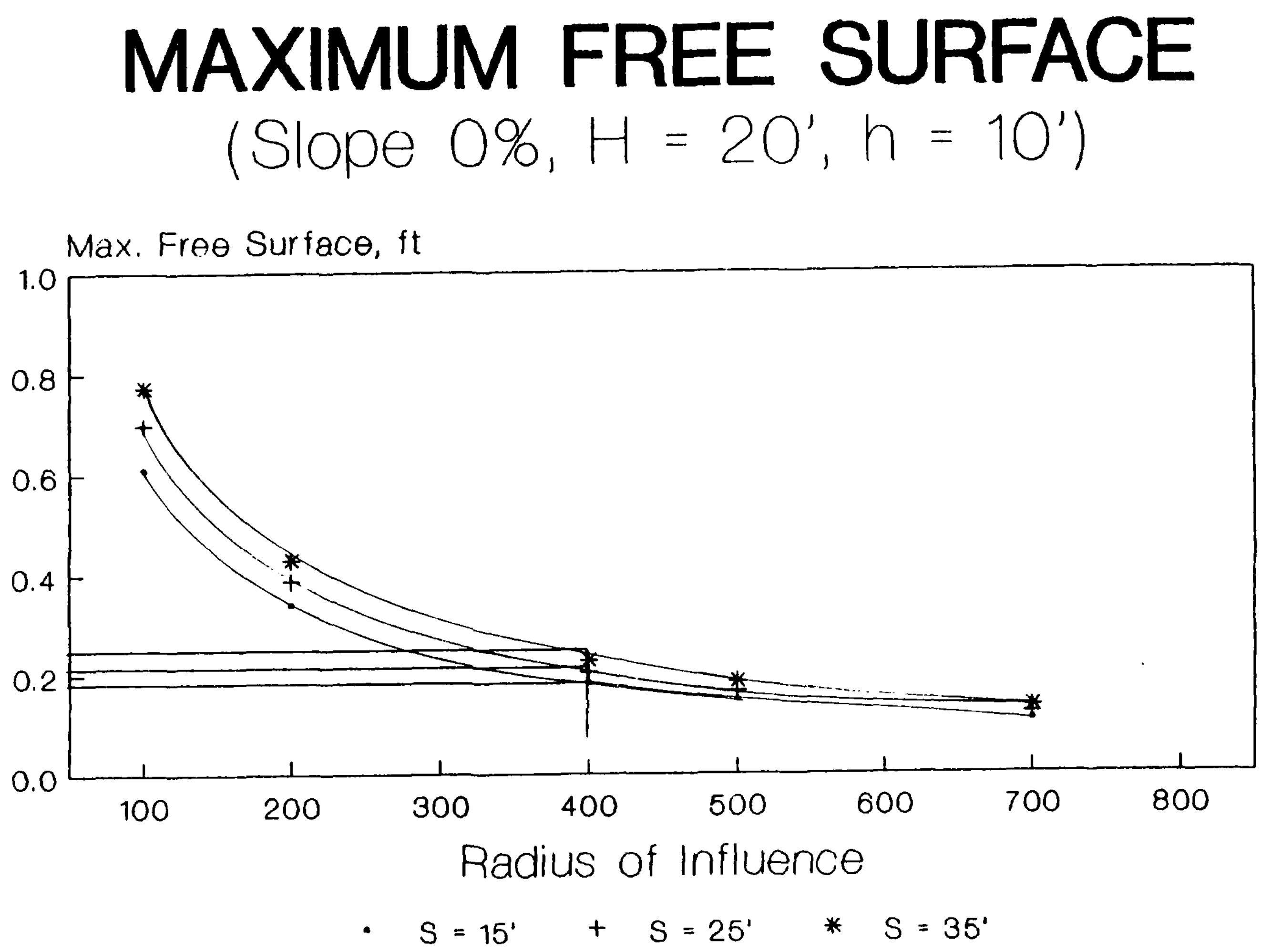

Fig. 3-10
Finding the Max. Free Surface
between trenches

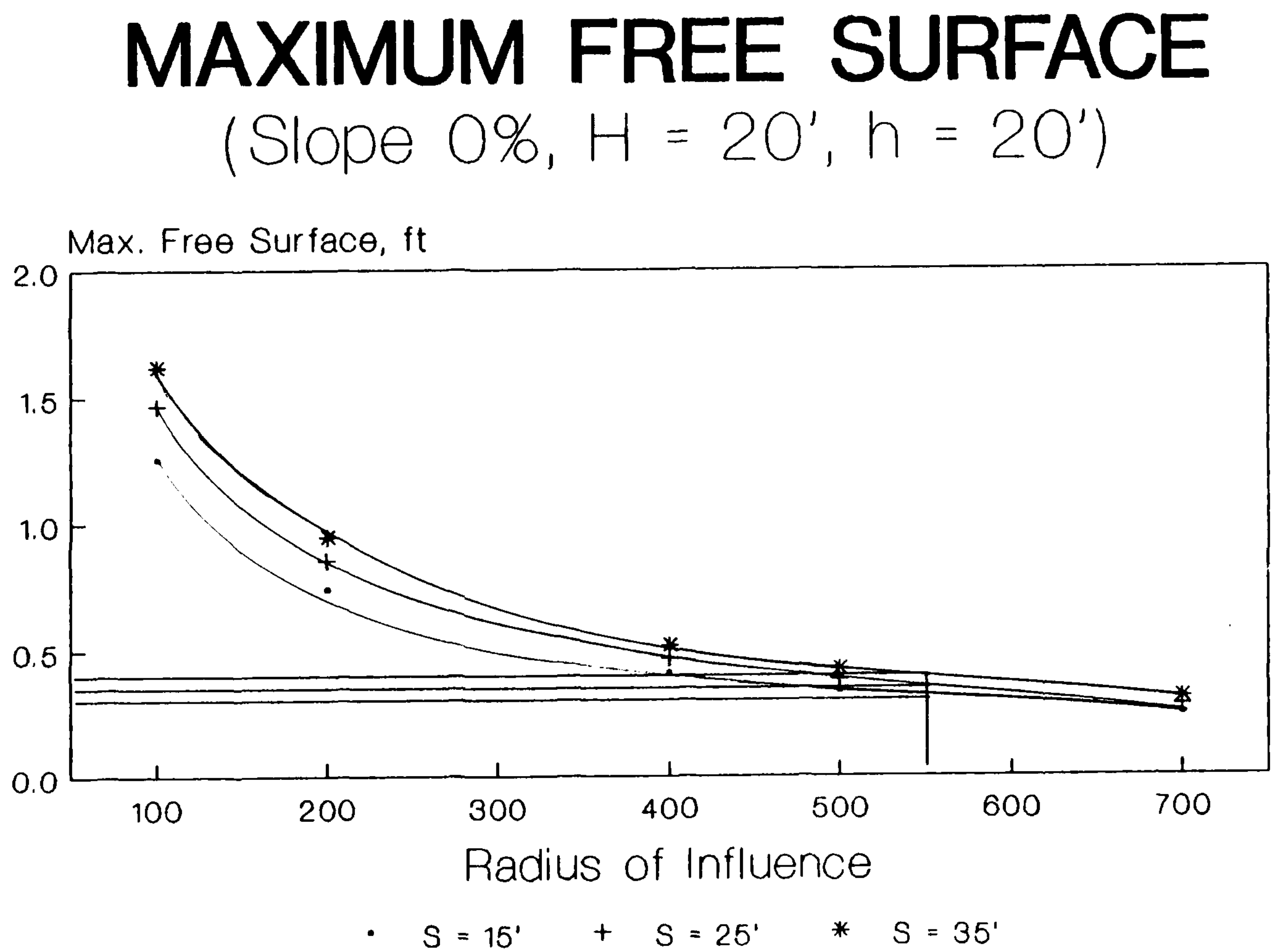

Fig. 3-11
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 0%, H = 60', h = 10')

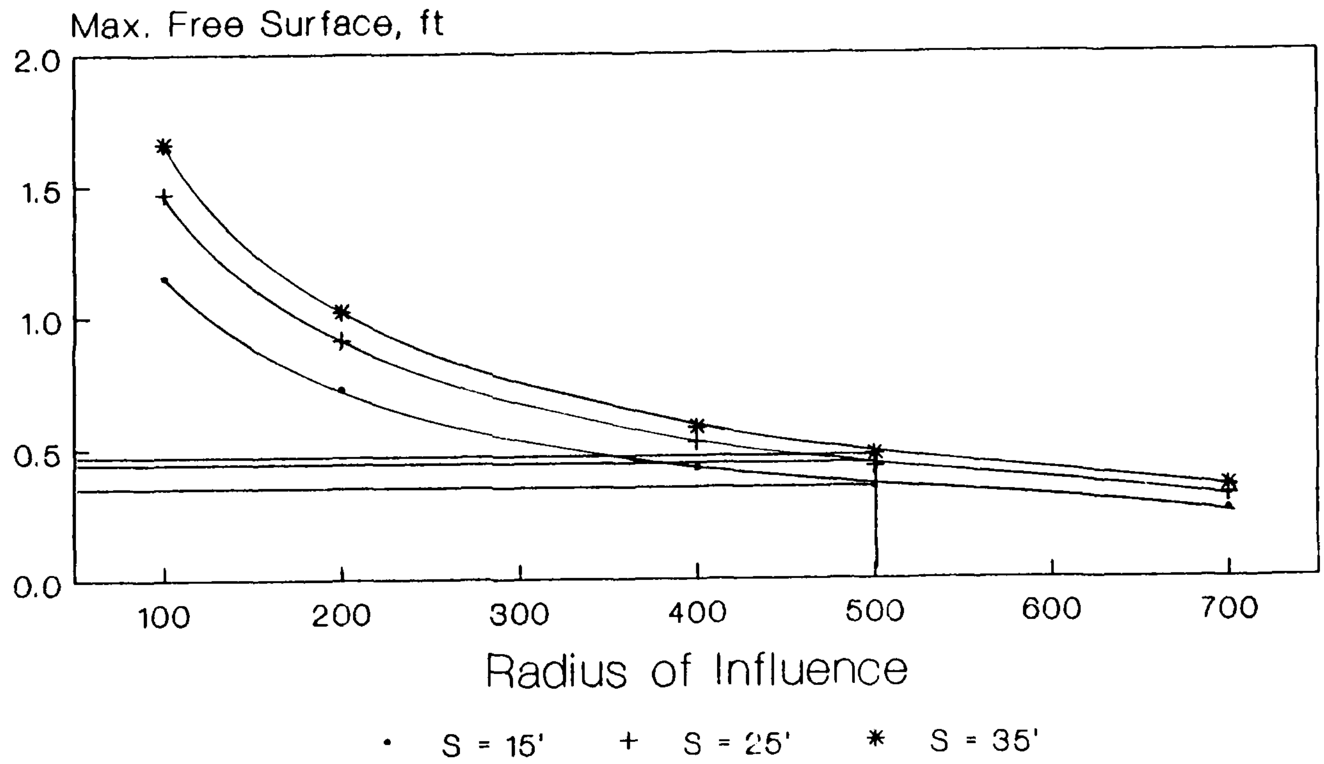

Fig. 3-12
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 0%, H = 60', h = 20')

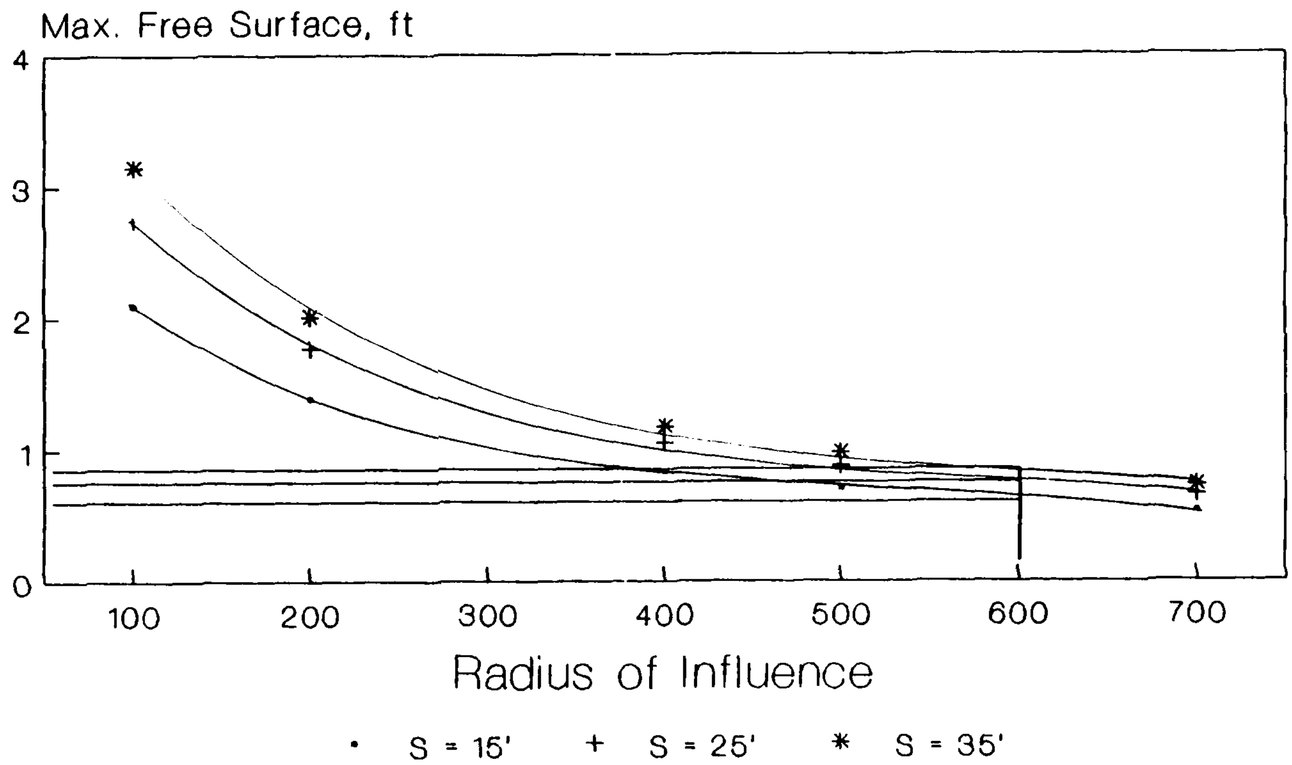

Fig. 3-13
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, H = 20', h = 10')

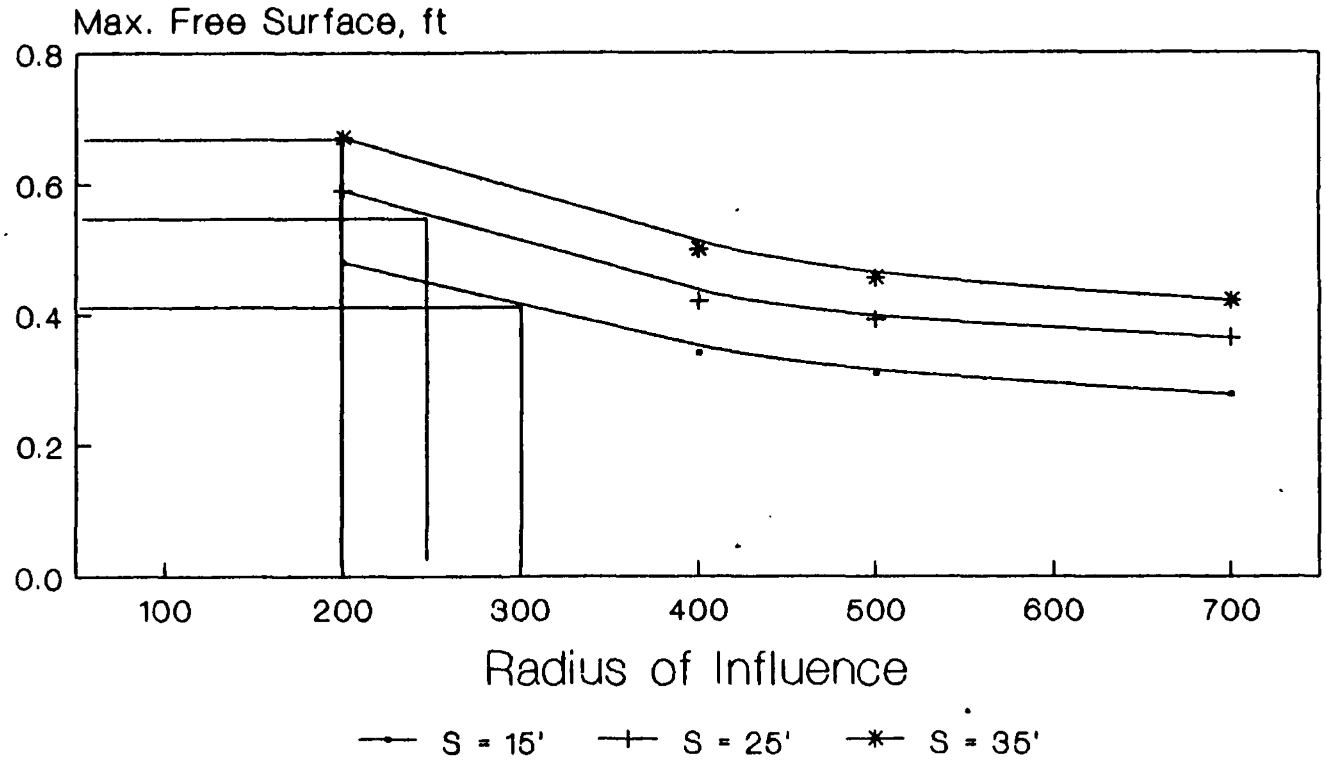

Fig. 3-14
Finding the Max. Free Surface
between trenches

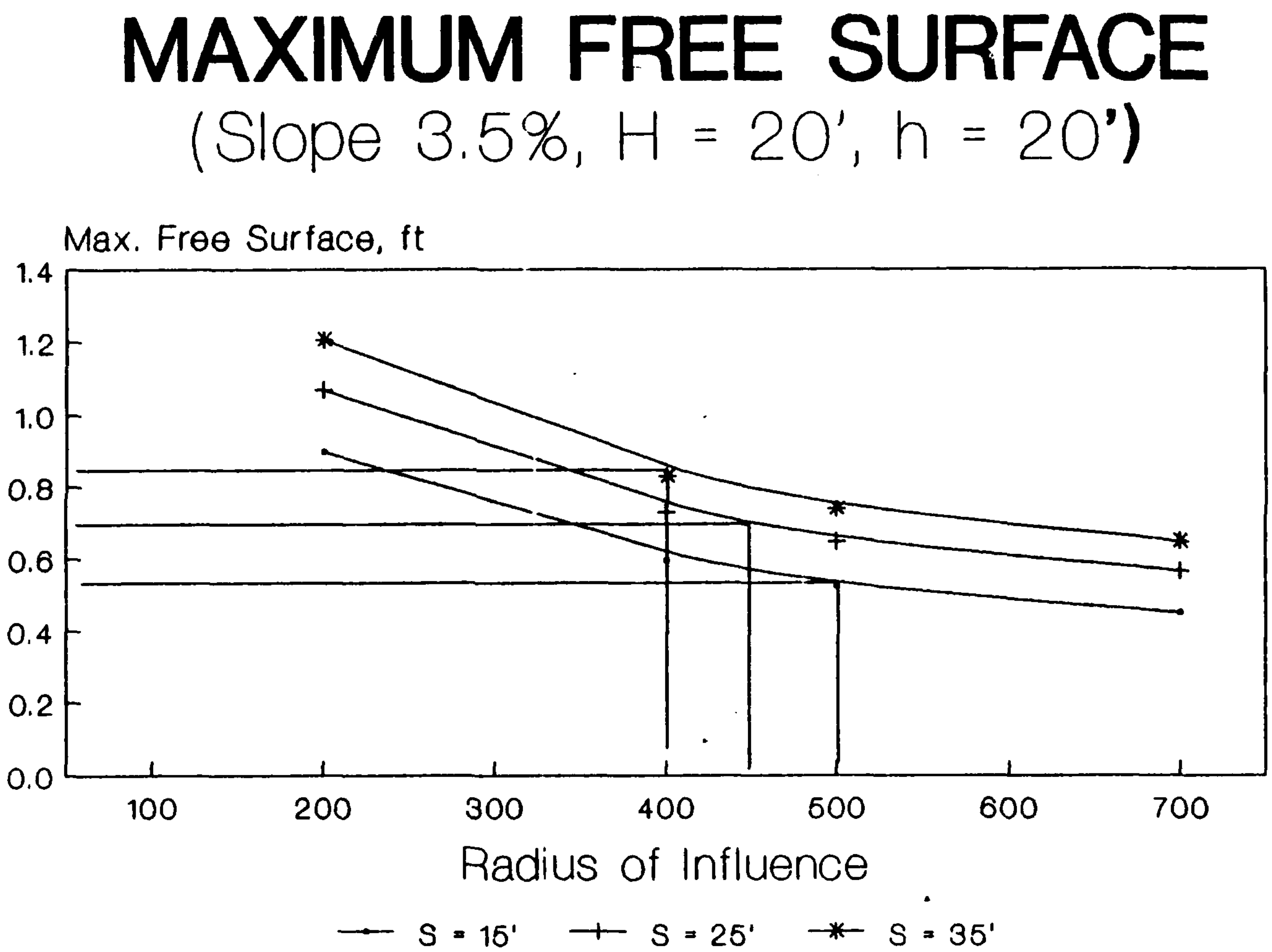

Fig. 3-15
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 3.5%, H = 60', h = 10')

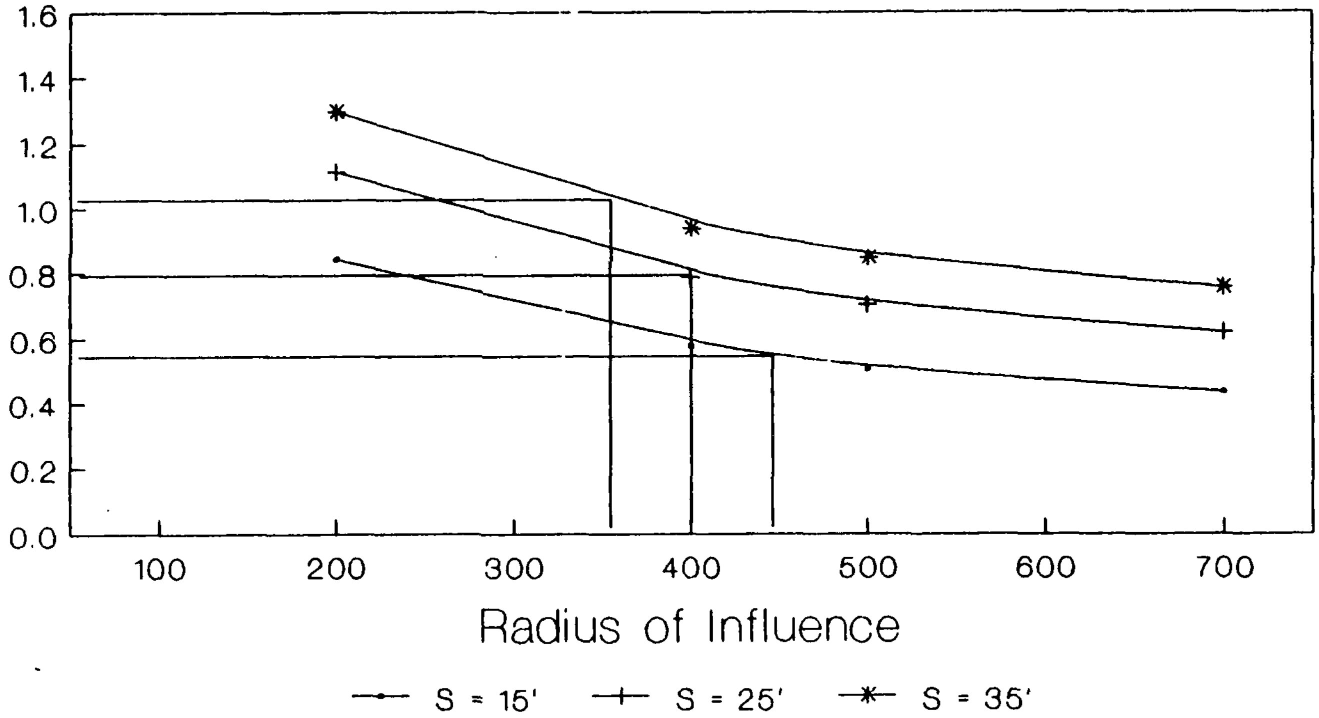

Fig. 3-16
Finding the Max. Free Surface
between trenches

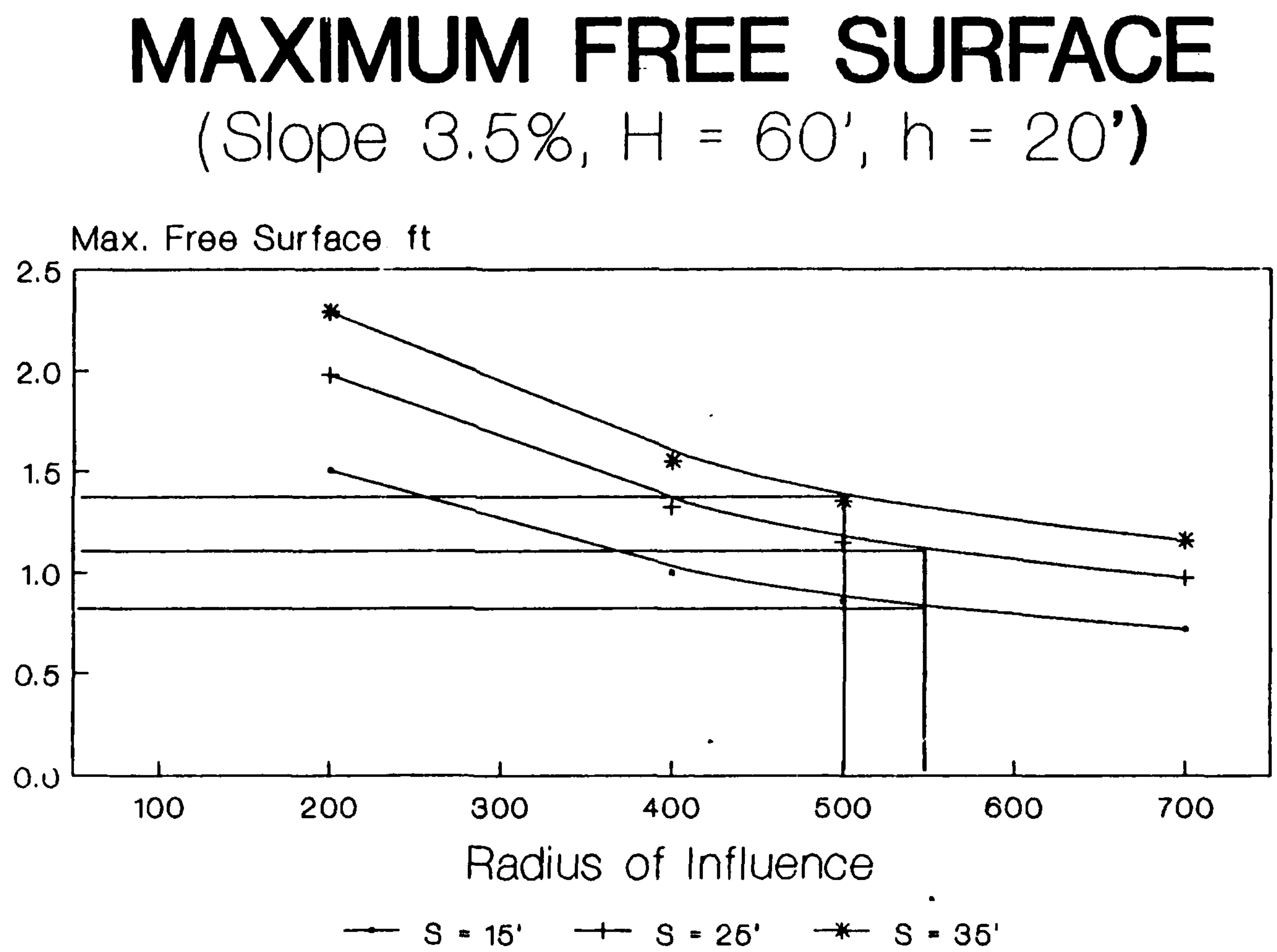

Fig. 3-17
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, H = 20', h = 10')

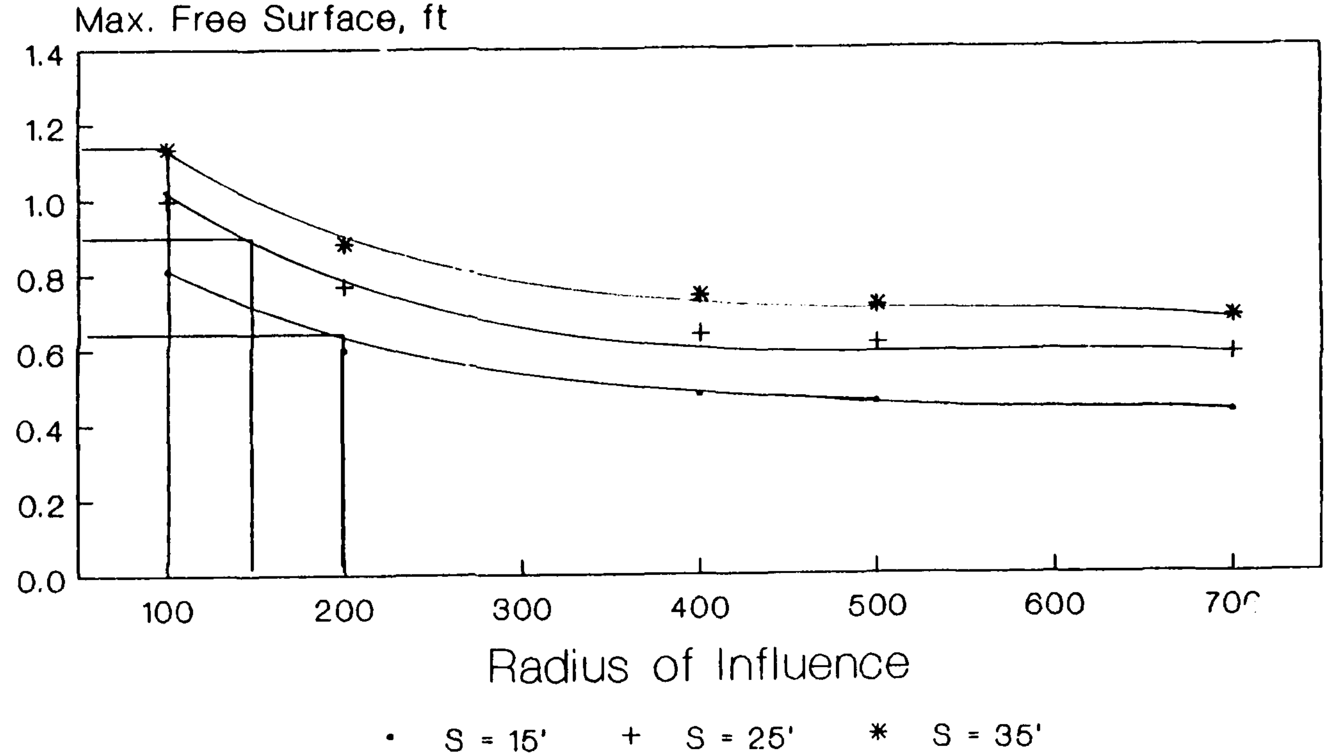

Fig. 3-18
Finding the Max. Free Surface
between trenches

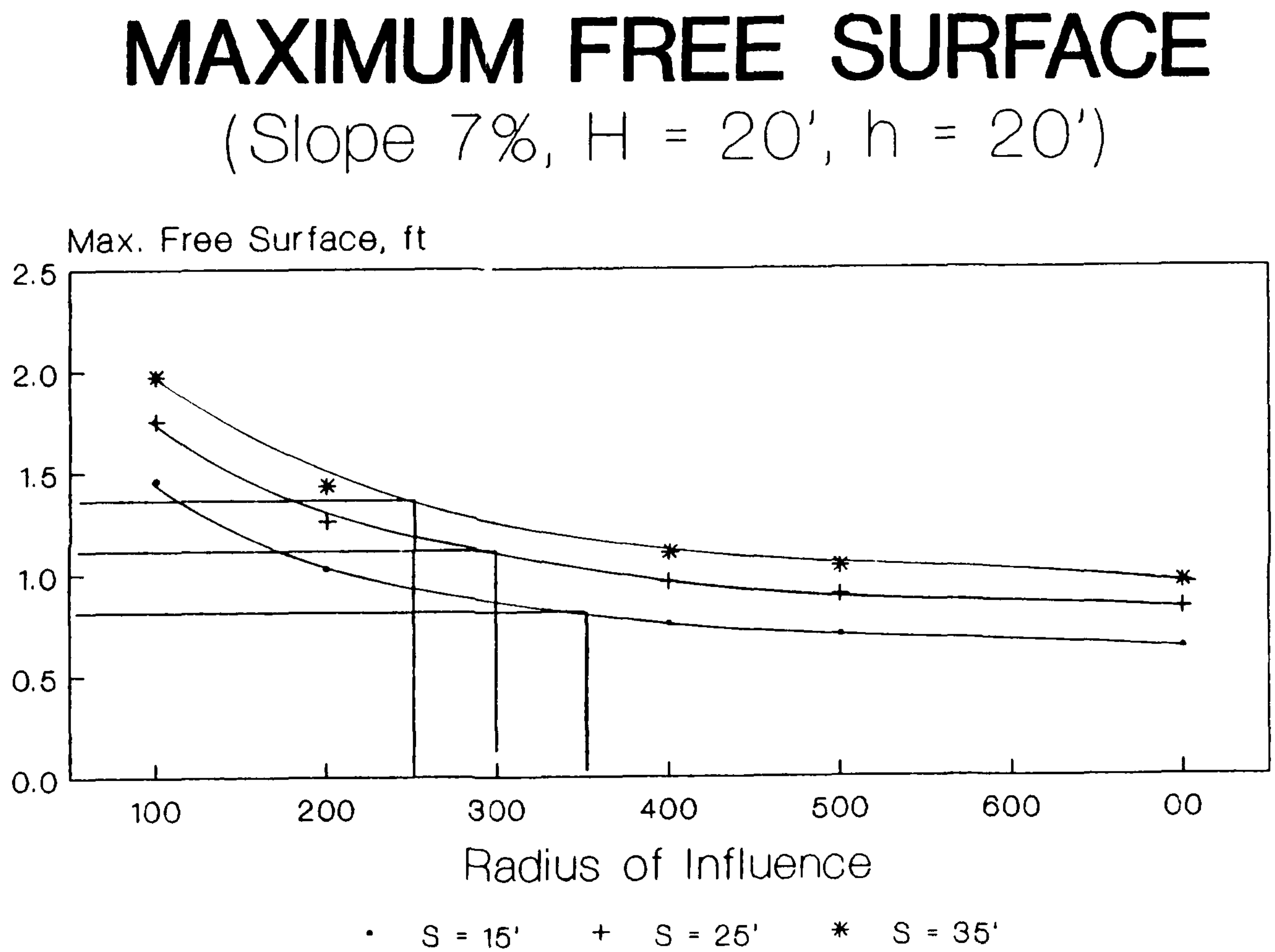

Fig. 3-19
Finding the Max. Free Surface
between trenches

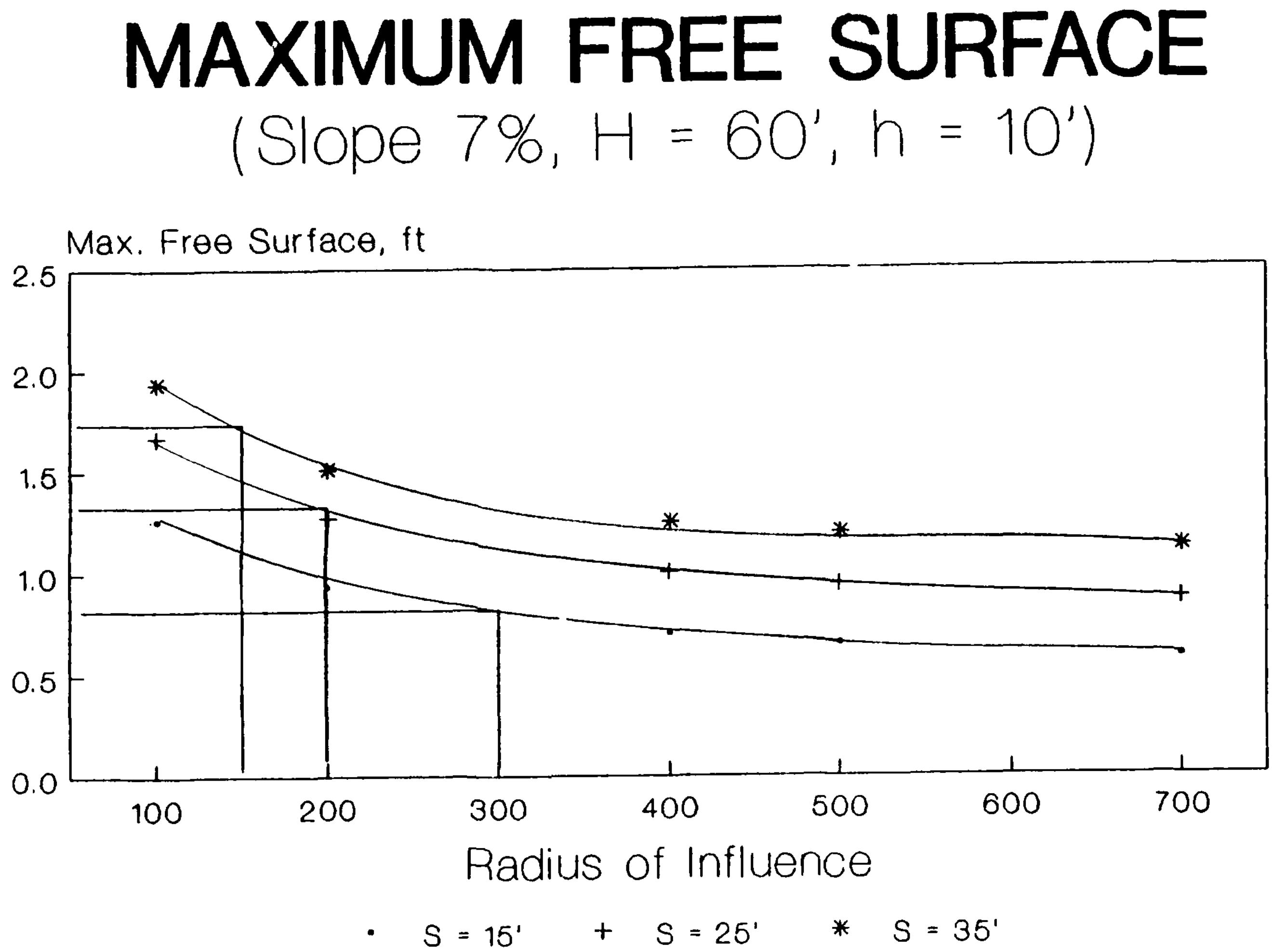

Fig. 3-20
Finding the Max. Free Surface
between trenches

MAXIMUM FREE SURFACE

(Slope 7%, H = 60', h = 20')

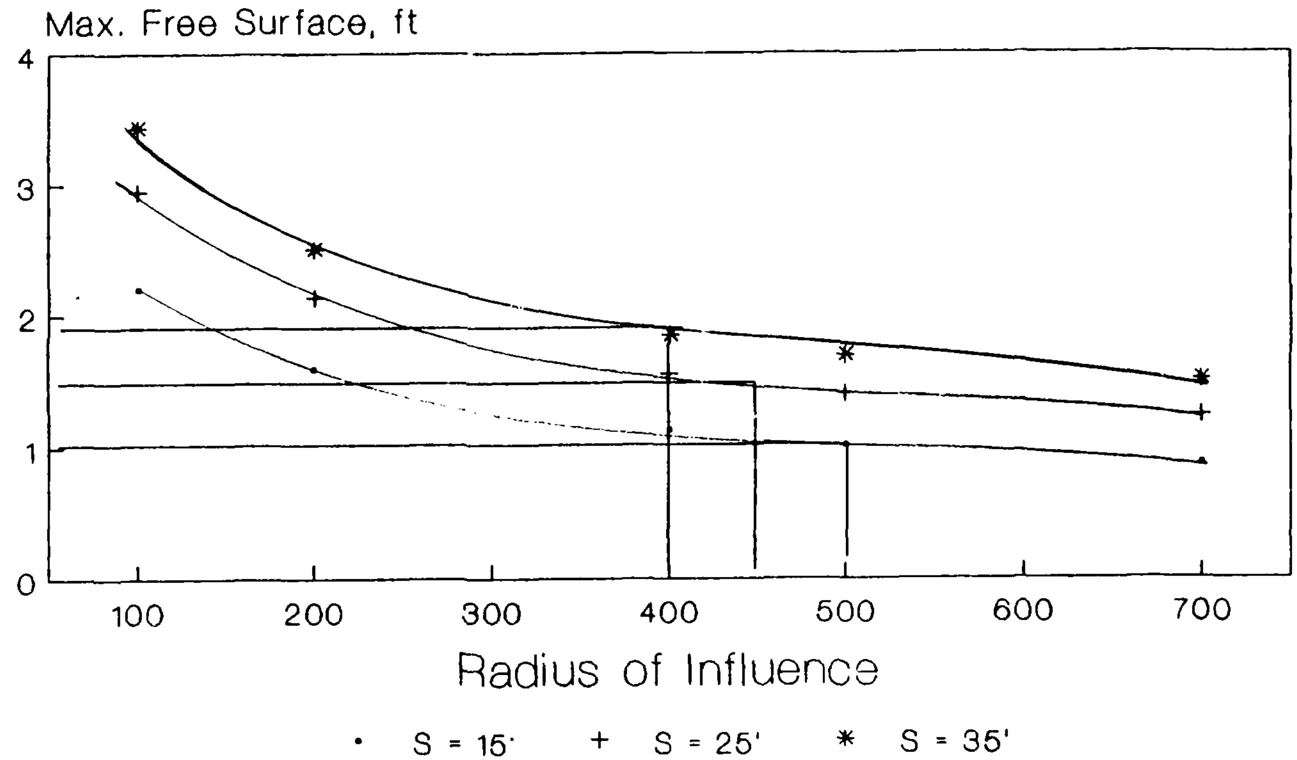

Fig. 3-21
Finding the Max. Free Surface
between trenches

V. Summary:

In summary there were three slopes considered, three spacings between drains, two elevations of trench and two free heads above the trench. That is thirty six geometries of problem, all considered under one horizontal and vertical hydraulic conductivity. While the physical dimensions of this problem are adequate to cover the majority of cases under which trench drains would be utilized, the single values of k leave room for further evaluation. With the use of dimensional analysis this study might serve to allow extrapolation of results for different hydraulic conductivities but, validation by further modeling is recommended.

CHAPTER 4

ANALYSIS OF TRENCH DRAIN DEWATERING

I. Introduction:

Modeling a foundation trench drain system with the a finite element analysis provides a myriad of results for many different conditions. For the analysis to be of use it must be presented so that future systems of trench drains can have capacities and limitations predicted from the results. This chapter is the presentation of results for use in prediction and selection of a trench drain system.

II. Results:

Chapter 3 details the input and output of this trench drain analysis. In Appendix A, Table A-1 summarizes the different variables and trench drain systems evaluated. From the data collected the total flow of a trench drain system with four drains in an isotropic soil can be determined for a range of design characteristics which are reasonable minimums and maximums. From this output information trends can be identified for the response to each variable.

The radius of influence was found from the measures described in Chapter 2. For each of the thirty six evaluated geometries of trench drain system four to six

computer models were run, each with a different trial radius of influence. Figures 2-1 through 2-12 show the results of these trials. As expected each trial of a lesser radius of influence predicted a greater total flow from the trench drain system. As the trial radius approaches the theoretically correct radius of influence the quantity of flow becomes unchanging and models the gravity flow condition accurately.

The spacing of trenches does not change the total flow of the trench drain system in a consistent pattern. The flow changed with other variables so that the single affects of spacing on flow is indistinguishable.

It is obvious that spacing directly influences the magnitude of the maximum free surface between trenches. On Table A-1 every combination of slope, trench elevation and free head has increasing maximum free surface with increasing spacing. This is consistent with expectations. Greater spacing decreases the influence of adjacent trenches. Figures 3-6 through 3-9 show that the maximum free surface in a sloping aquifer is strongly influenced by the upstream trench. The influence is even more strongly exhibited with increasing space. A larger spacing of trenches further isolates the upstream trench from drawdown influence from the inboard trenches.

In all cases the radius of influence decreased with increased aquifer slope. With greater slope, spacing of

the trenches exhibited the affect of decreasing the radius of influence. The dominant factor was the slope. The radius of influence was unchanging with spacing when the slope was zero.

Total flow did increase with the increasing slope of aquifer but, the magnitude of the change varied with the other variables so that a single affect from slope cannot be determined.

The maximum free surface increased consistently with the aquifer slope. The maximum free surface increased by 50%, for each 3.5% incremental change of slope, in every geometry considered.

Impact of different free heads above the trench was quite consistent and was normally coupled with the elevation of the trench. For constant elevation of trench the radius of influence increased with free head. In a similar manner the total flow increased with free head, with the magnitude of change impacted by the variables considered. The maximum free surface also showed a significant increase with free head when the elevation of the trench is constant.

For a constant free head with changing elevation of trench the same trends in radius of influence, total flow and maximum free surface can be seen. The magnitude of the change is not as great and the greater influence of free head can be inferred.

In this study only one drain width was considered and so the individual impact of a changing width cannot be determined. Only one vertical and horizontal hydraulic conductivity combination was studied and all studies were done on a four trench system so the affects of these single variables cannot be reported.

The many results of this study show the necessity for a form of dimensional analysis in evaluating a model affected by many variables. Some trends can be predicted from a couple of variables but, a complete prediction of performance or trend is not possible without a dimensional analysis.

III. Results of Predictive Formulas:

It is not surprising that no single numeric method exists for the evaluation of a trench drain system of four drains, in a sloping aquifer. This study attempts to provide that solution but, do other, existing solutions serve the need? In Chapter 2 several formulas were referenced in the discussion of determining a radius of influence. In this section several formulas are evaluated. The formulas below are presented with the variables used in this study rather then as presented in the source. A comparison of the results for the below methods with the results of the finite element analysis are in Table 4-1.

a.) $Q_p = (.73 + .27(h/(h+H))\ Kx((h+H)^2 - h^2)/L$

Q_p=total flow, h=free head, H=trench elevation, x=trench length, K= permeability, L= radius of influence (use consistent units)

The above formula (Leonards, pg 273) has the advantages of being for a partially penetrating slot in an unconfined aquifer. The disadvantages are that it has no provisions for a sloped aquifer, multiple trenches, trench width or means for calculating the maximum free surface. The radius of influence is a value of input to this formula.

b.) Figures 36, 61, 68 and 69 (Moulton)

The referenced charts offer allowances for sloping aquifer, two drains, partial penetration of the aquifer and a means of calculating a maximum free surface between drains. Some disadvantages of the methods are the lack of trench width, no allowance for more then two drains and a half space solution to the zero slope portion. The radius of influence is an input variable to solution. As listed in Chapter 3 the recommended radius of influence is 3.8*h. This value yields a maximum radius of influence of 76 feet for this study. This value was much less then used throughout the study and yielded results far greater then predicted from the finite element analysis. In Table

4-1 the radius of influence used was that from the finite element analysis which yielded results much closer to those of the other calculations.

c.) $Q/x = K((H+h)^2 - h^2)/L$ ((a)Powers, pg 100)

Q= total flow, x= trench length, K= permeability, H= trench elevation, h= free head, L= radius of influence (Use consistent units)

This method is a traditional trench solution. It does not make allowance for partial penetration of the aquifer, multiple trenches, trench width or aquifer slope.

d.) $G = S_y Lq/KH^2$ and figures 18(b) and (c) (Freeze, pg 261) G= dimensionless product, S_y= Specific Yield, L= radius of influence, q= total flow per unit width, K= permeability, H= aquifer thickness (use consistent units)

This solution is for a partially penetrating trench. Once again this method makes no provision for multiple trenches, trench width, sloping aquifer. In addition the Specific Yield is used adding another variable, this one normally varying between .01 and .3 (Freeze, pg 61).

Each of the above methods have several disadvantages and were not developed for use in the evaluation of a trench drain system. Assuming that the finite element analysis is the most accurate of the means of evaluation tried it is obvious in Table 4-1 that no single formula

TABLE 4-1 Summary of Predictive Methods

Summary	A	B	C	D
Slope	0	3.5	3.5	7
Spacing (ft)	35	15	35	25
Trench El (ft)	60	20	60	20
Free Head (ft)	10	20	20	10
(Mansur, pg 273)				
total flow (ft^2/day)	0.5	0.46	0.81	0.55
(Moulton, pg 120 & 130)				
total flow (ft^2/day)	0.49	0.22	0.73	0.42
(Powers, pg 100)				
total flow (ft^2/day)	0.66	0.53	1.02	0.66
(Freeze, pg 261)				
total flow (ft^2/day)	5.88	0.64	5.12	2
Aral Seepage Program				
total flow (ft^2/day)	0.14	0.19	0.25	0.27
Radius of Influ (ft)	500	500	500	150
Trial Radius 200'				
Total Flow (ft^2/day)	.3	.45	.54	.26

approximates the solution to the problem very closely. Of the evaluated methods the Moulton method, using the radius of influence as determined by the finite element analysis was the most accurate. It is worth noting that with no other means of selecting a radius of influence the value determined in this study was used for each method. This approximation would certainly affect the results. Appendix E is a discussion of the affect of arbitrary selection of radius on total flow and free surface height.

IV. Prediction of Trench Drain Performance:

The prediction of total flow and maximum free surface is possible through the use of results presented in a dimensionless form. As a trial some runs were done to explore the affects of anisotropy and number of trenches. These results are discussed below.

Any prediction of flow characteristics requires an evaluation of the radius of influence. Figures 4-1 through 4-3 are useful for predicting the radius of influence from the trench elevation, free head, slope of aquifer and the trench spacing. These figures are only appropriate for an isotropic condition in a four trench system with a trench width of 1.5'. Use of the figures will frequently require several interpolations.

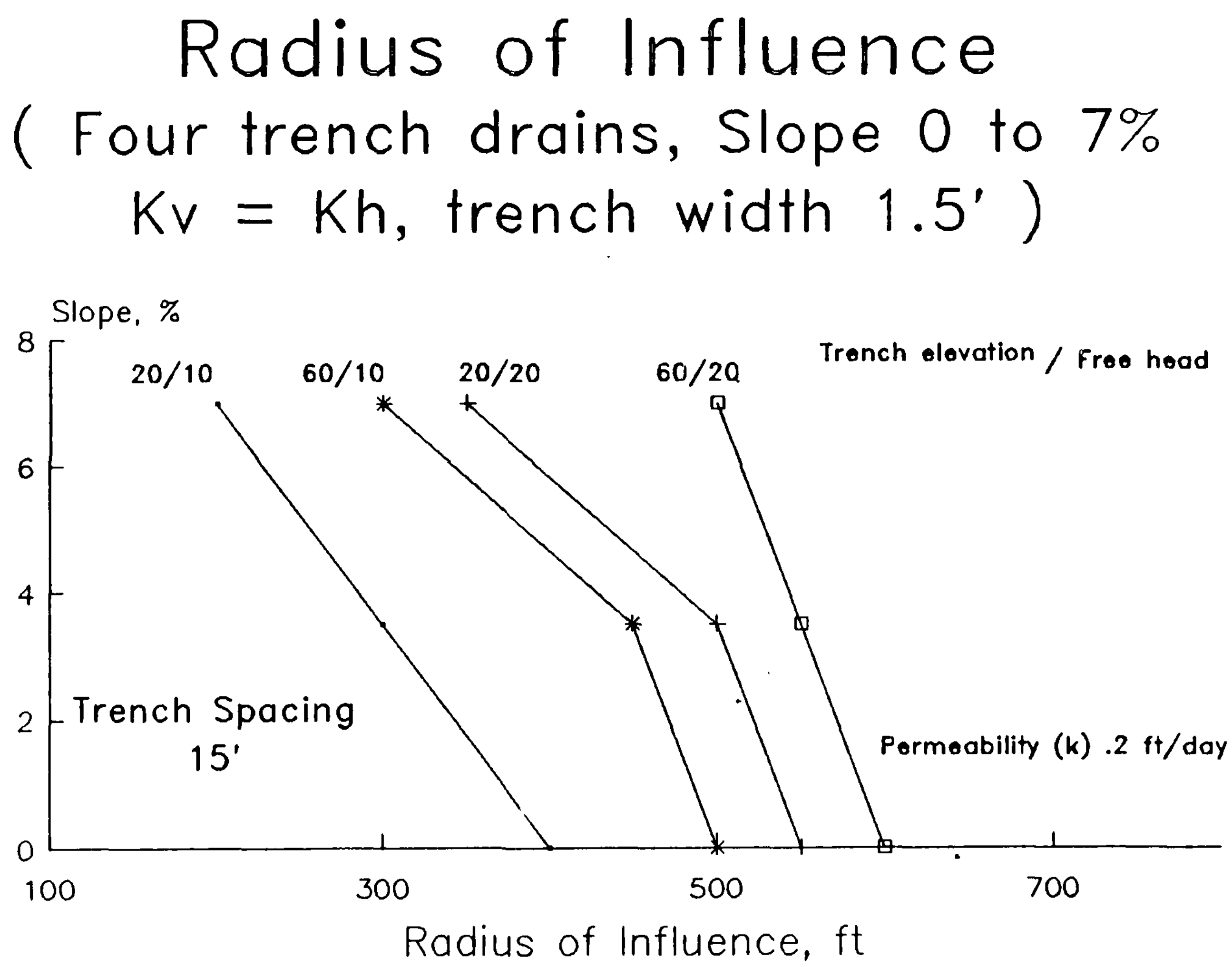

Fig. 4-1
Predicting the radius of influence

Radius of Influence
(Four trench drains, Slope 0 to 7%
Kv = Kh, trench width 1.5')

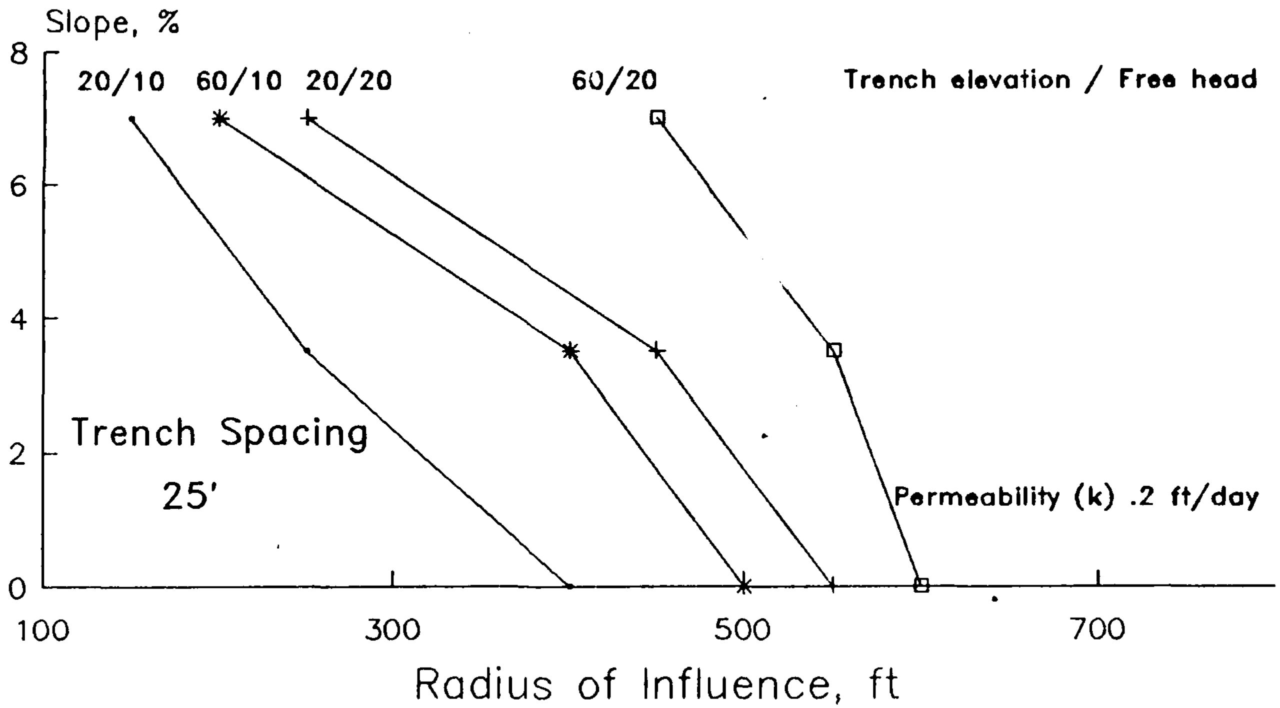

Fig. 4-2
Finding the radius of influence

Radius of Influence
(Four trench drains, Slope 0 to 7%
Kv = Kh, trench width 1.5')

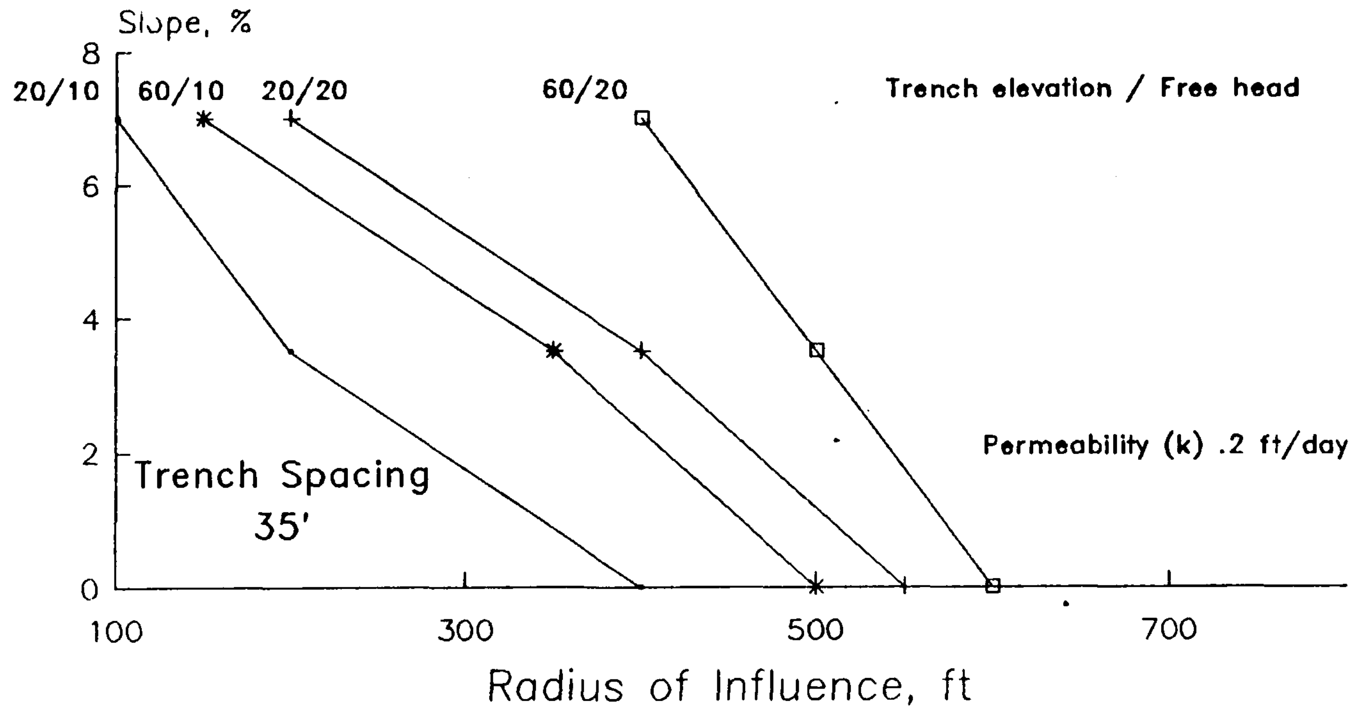

Fig. 4–3
Finding the radius of influence

To use figures 4-1 through 4-3 the following example will be useful.

Example 4-1: Find the radius of influence for a four trench system with trench width of 1.5' and K_v/K_h = 1 with K = .2 ft/day. The trench elevation is 40 feet, the free head is 15 feet, the trench spacing is 30 feet and the aquifer slope is 4%.

a. Figure 4-4 is annotated from Figure 4-2. Follow this figure through the following steps.

b. At slope = 4% on Figure 4-2 interpolate between the lines labeled 20/10 and 20/20 as well as between 60/10 and 60/20. These are the points for trench elevations of 20 and 60 feet with a free head of 15 feet. The radii of influence for these two points are 330 feet and 456 feet.

c. Again at slope = 4% interpolate between the above two points to find the radius of influence for a trench elevation of 40 feet and a free head of 15 feet with a spacing of 25 feet. This radius of influence is 394 feet.

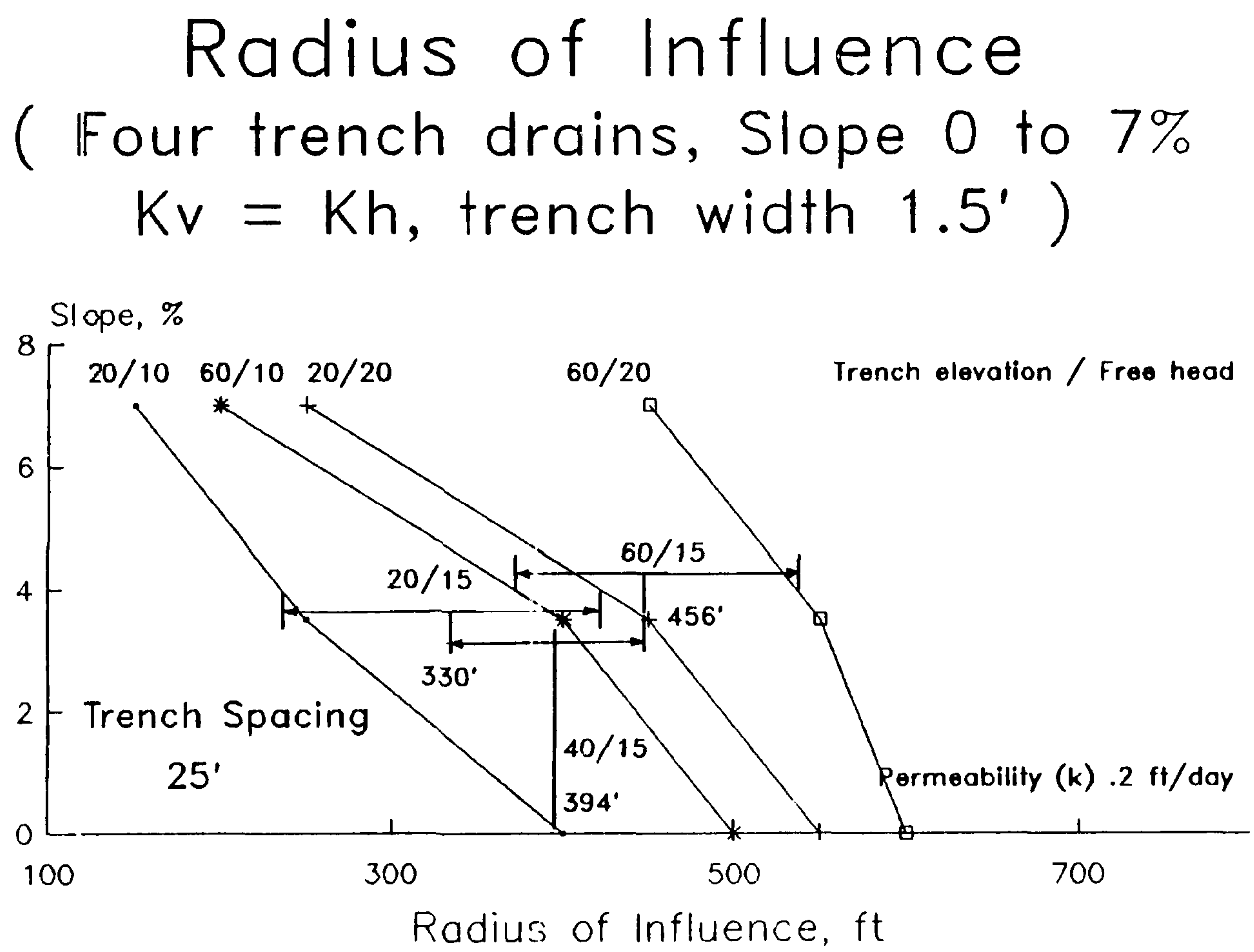

Fig. 4-4
Finding the radius of influence
for example 4-1

d. Follow the above procedure again on Figure 4-3 to get a radius of influence of 344 feet when spacing is 35 feet.

e. For a spacing of 30 feet interpolate between the results of steps c. and d. above to get a final predicted radius of 369 feet.

As an alternate method a rough selection of 350 or 400 feet will not make a significant difference in the following calculation method. As discussed in Chapter 2 the radius of influence is an extremely variable value, often approximated only within an order of magnitude. One suggested method (Moulton, pg 66) has the radius of influence estimated as 3.8 times the free head. In this example that would predict a radius of only 53 feet, one seventh of that from this study but, within one order of magnitude.

In Chapter 2 the derivation of the dimensionless product used in this study was reviewed. The product which best presented the behavior of total flow and maximum free surface with the changing variables of the problem geometry was:

$$Ld/h(h+H) \qquad (2)$$

Where L = radius of influence, d = trench width, h = free head and H = trench elevation as shown on Figure 3-4. Using consistent units for the variables yields a dimensionless product.

Figures 4-5 and 4-6 are total flow and maximum free surface, respectively against the dimensionless product for the considered geometries. In both plots an acceptable curve fit is possible. The points are aligned with the largest aquifer slope to the left and the zero sloped aquifer to the right. This observation is for interest only as the dimensionless product provides sufficient accuracy with the sloping aquifer influence represented by the values of total flow, maximum free surface and radius of influence. From the previous example:

a. Calculate Ld/h(h+H). For this problem using the above L = 369 feet, Ld/h(h+H) = 369'*1.5'/15'(15'+40') = .671

b. From Figure 4-5 total flow q = .25 ft^2/day

c. From Figure 4-6 maximum free surface F = .9 ft

As a check of the accuracy of this method to predict the output of the finite element analysis six sample runs were conducted. The values of the variables and the results of the finite element analysis are shown in Table

TOTAL FLOW

(Four trench drains, 0 to 7% slope, Kv = Kh, trench width 1.5')

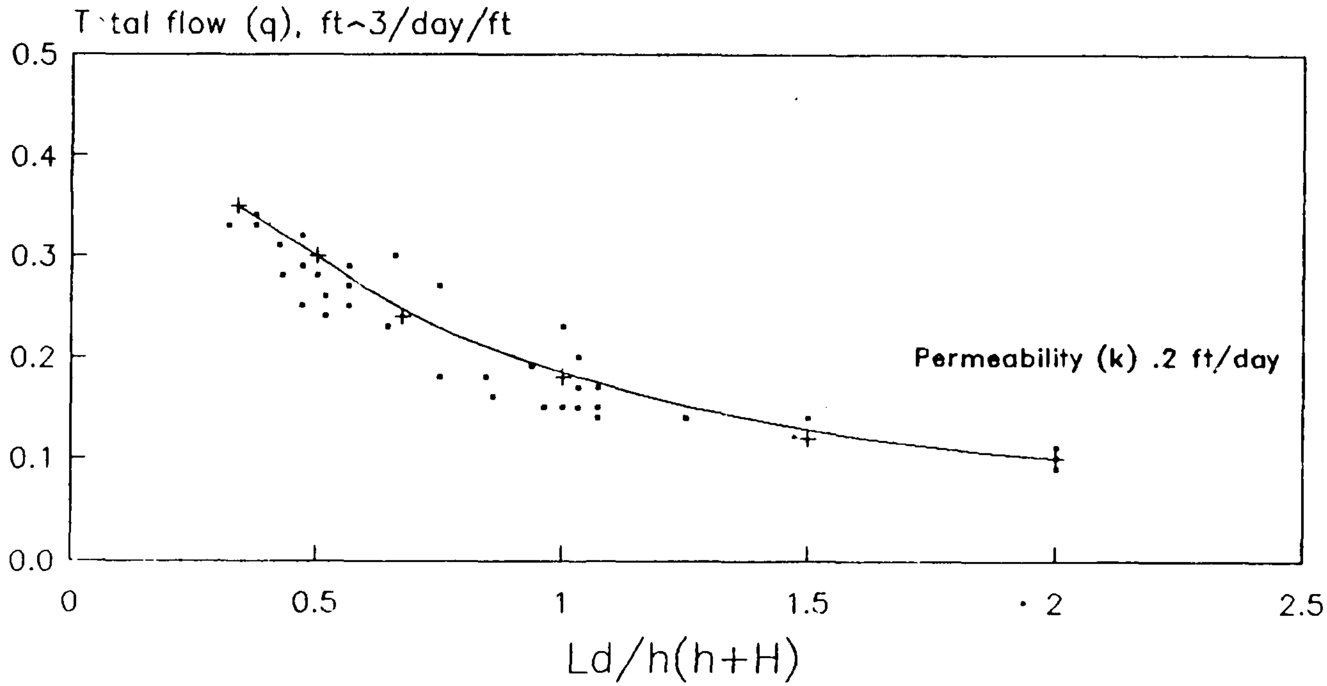

Fig. 4-5
Predicting flow from a dimensionless product

MAXIMUM FREE SURFACE
(Four trench drains, Slope 0 to 7%
Kv = Kh, trench width 1.5')

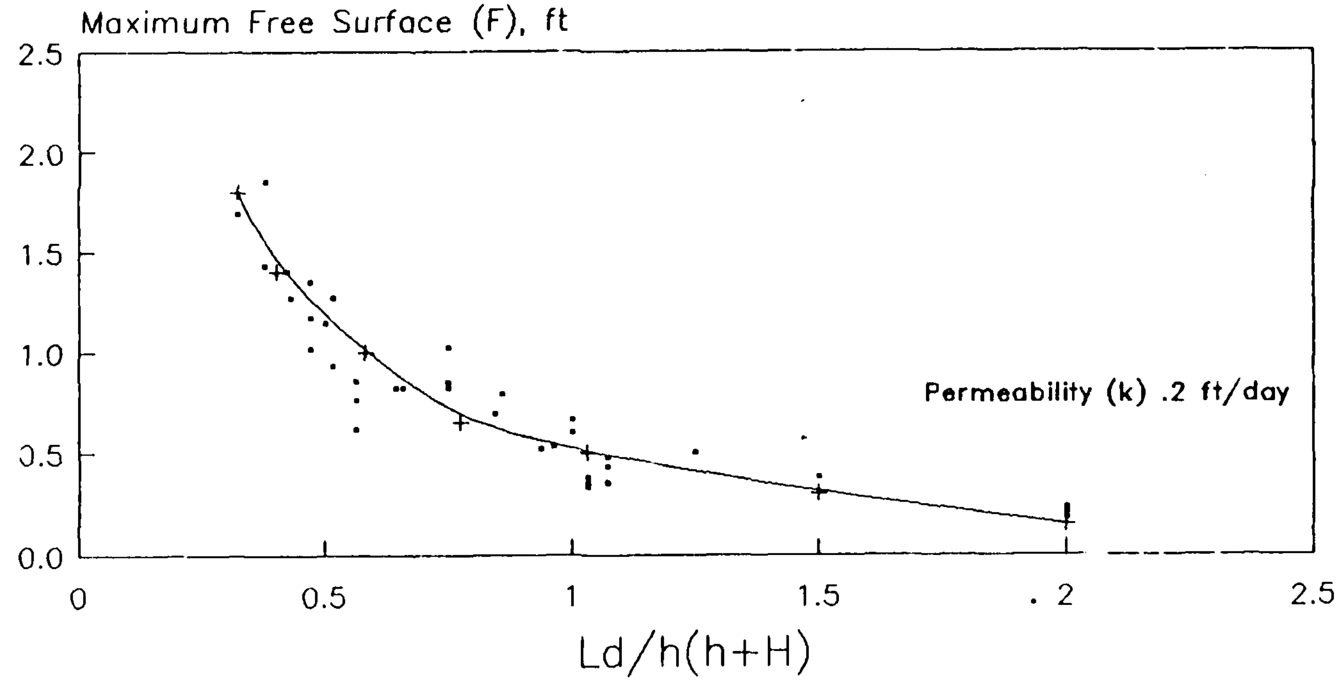

Fig. 4-6
Finding the maximum free surface
from a dimensionless product

A-2. For this analysis three trial radii of influence were used for each sample run. The theoretically correct radius of influence, total flow and maximum free surface were taken from plots similar to Figures 2-1 and 3-10.

The determination of the theoretically correct radius of influence is done under an arbitrary standard to an accuracy of fifty feet. From Table A-2 the prediction of total flow and maximum free surface agree with the results of the finite element sample runs. This is excellent accuracy in selecting the radius of influence. This method is acceptable for an isotropic soil with a four trench system.

Figures 4-5 and 4-6 were prepared assuming an isotropic condition. As a matter of interest several finite element runs were done modeling a four drain system with various conditions of anisotropy. Normally soils are anisotropic with K_v/K_h between .1 and .33. The results of these sample runs are shown on Figures 4-7 and 4-8, where the affects of differing hydraulic conductivity and anisotrophic soil are explored.

From Figure 4-7 it appears that different lines, nearly parallel, exist for a four drain systems with the line of largest total flow having the highest hydraulic conductivity and the line of lowest flow with the lowest hydraulic conductivity. The lines of differing conductivity may converge to the left side of the plot.

TOTAL FLOW

(Four trench drains, 0 to 7% slope, Kv $\neq$ Kh, trench width 1.5′)

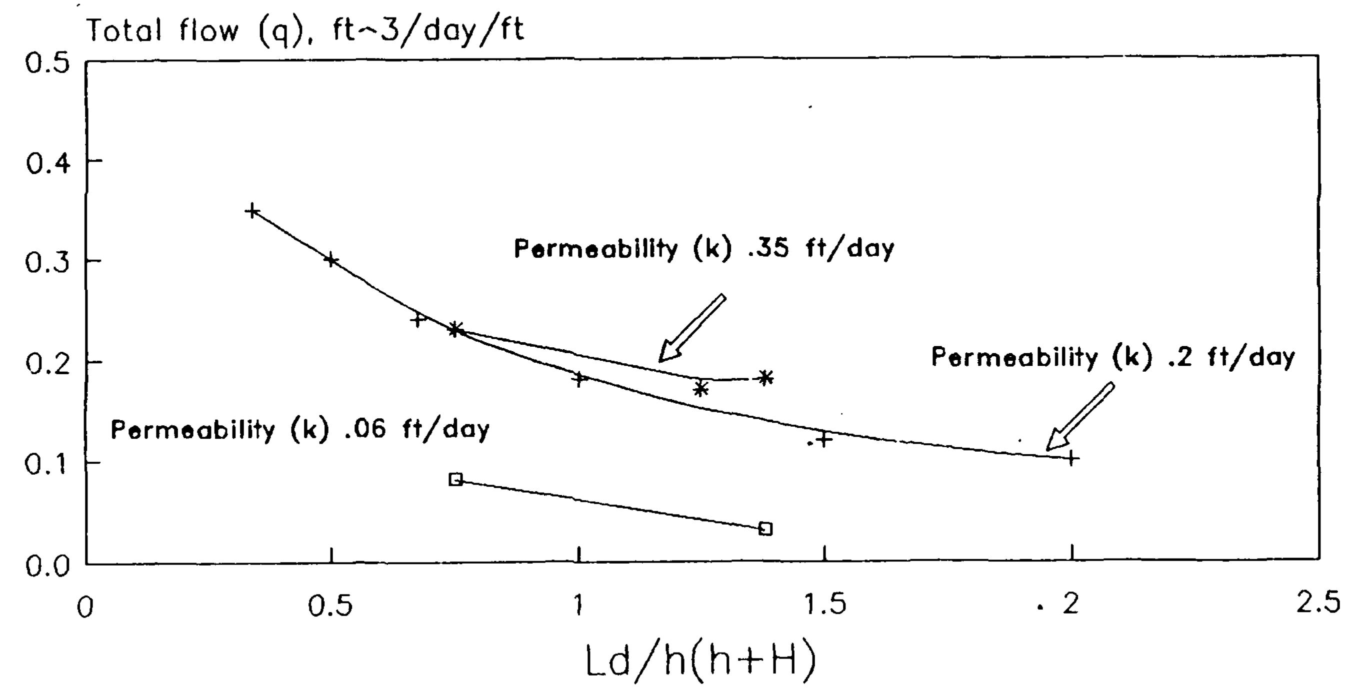

Fig. 4–7
Permeability and Flow with a dimensionless product

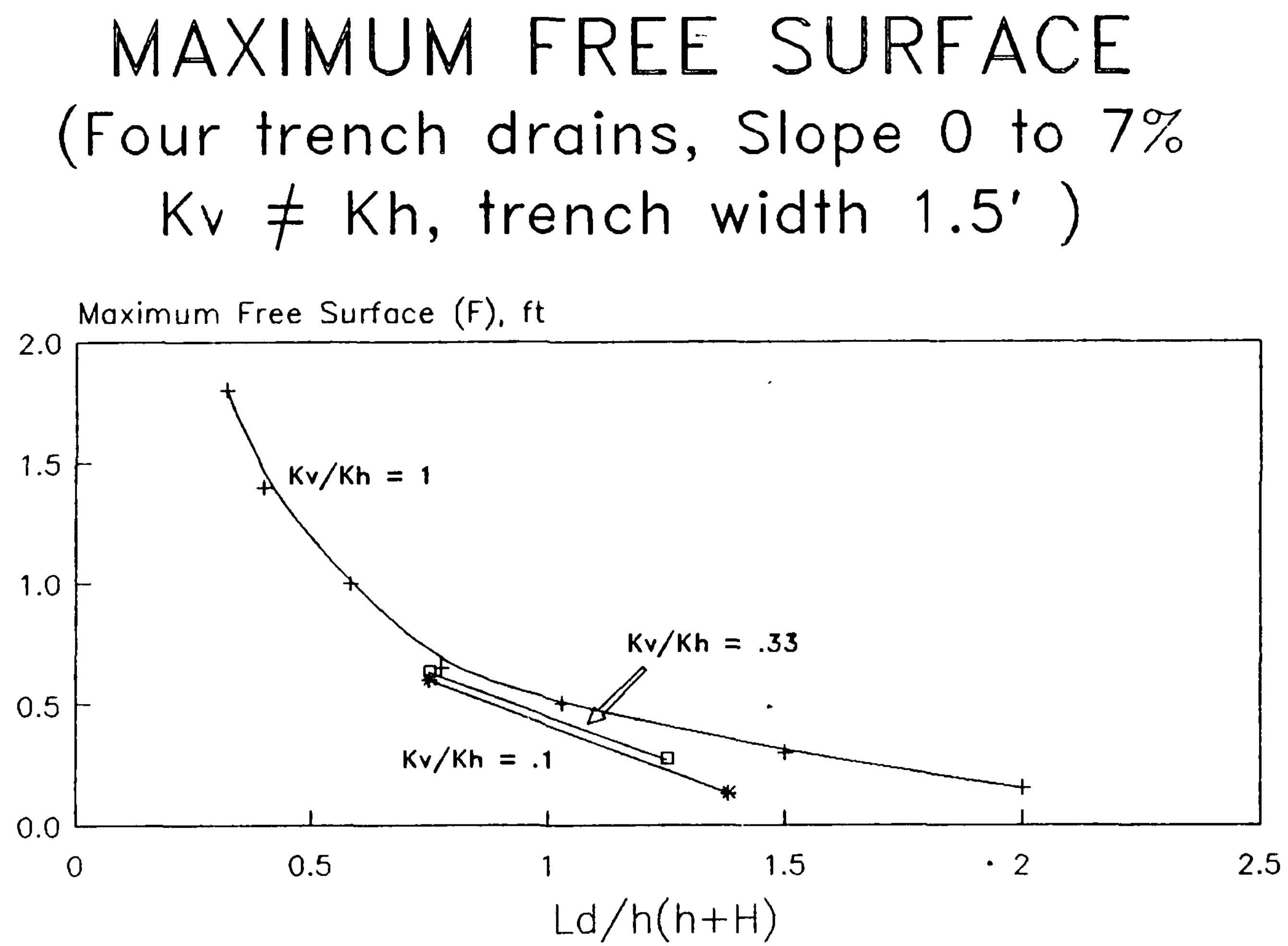

Fig. 4–8
Anisotropy and maximum free surface
from a dimensionless product

The degree of anisotropy appears to have no consistent pattern.

Figure 4-8 shows the opposite influence. The degree of anisotropy, represented by K_v/K_h, would have parallel lines with decreasing maximum free surface as the degree of anisotropy decreases. The lines of this plot may also converge to the left as Ld/h(h+H) decreases.

Another area of interest is the affect of a differing number of trench drains. As a means of predicting the ultimate affect of systems with more or less drains then the four evaluated. Figures 4-9 and 4-10 show the results of three runs of a three trench system. While not conclusive it is likely that the line for a three trench system is just below the four trench line. With further study it might be possible to extend the results of a four drain analysis based on the paralleling trends of lines for the different trench configurations.

TOTAL FLOW

(3 & 4 trench drains, 0 to 7% slope Kv = Kh, trench width 1.5')

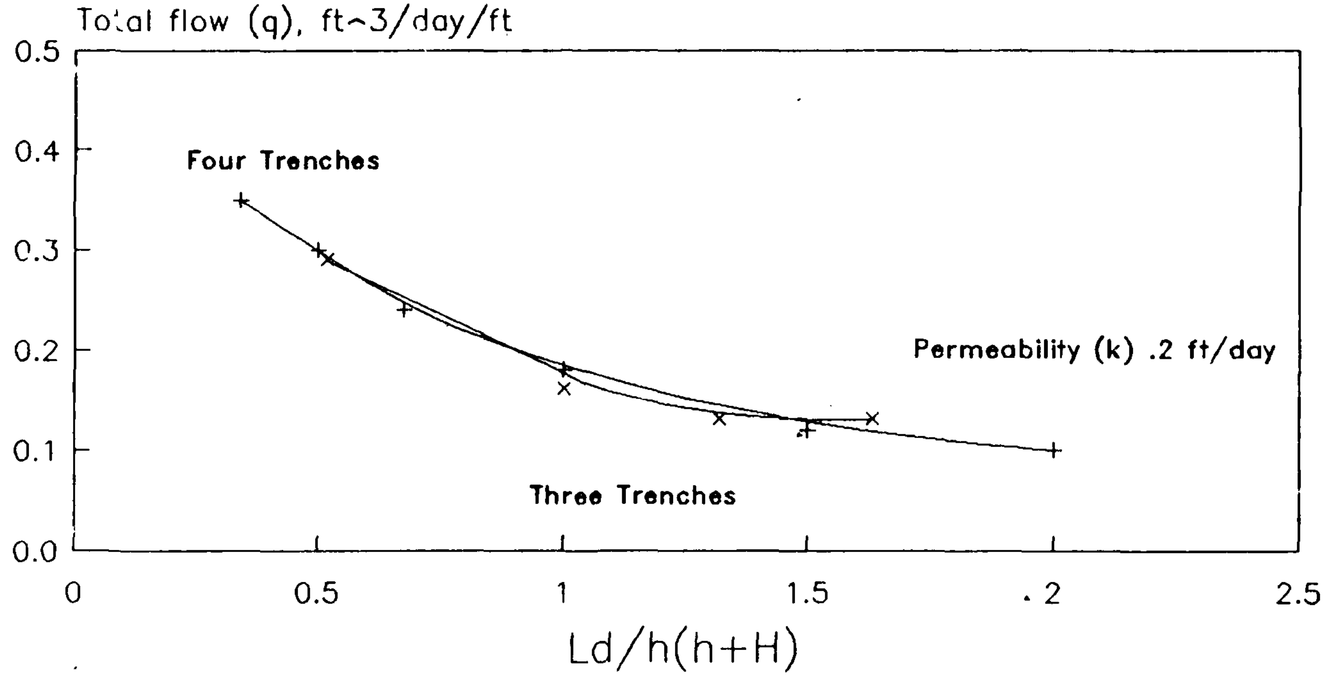

Fig. 4–9
Comparison of Three Drain System
in dimensionless product

MAXIMUM FREE SURFACE

(3 & 4 trench drains, Slope 0 to 7%
Kv = Kh, trench width 1.5')

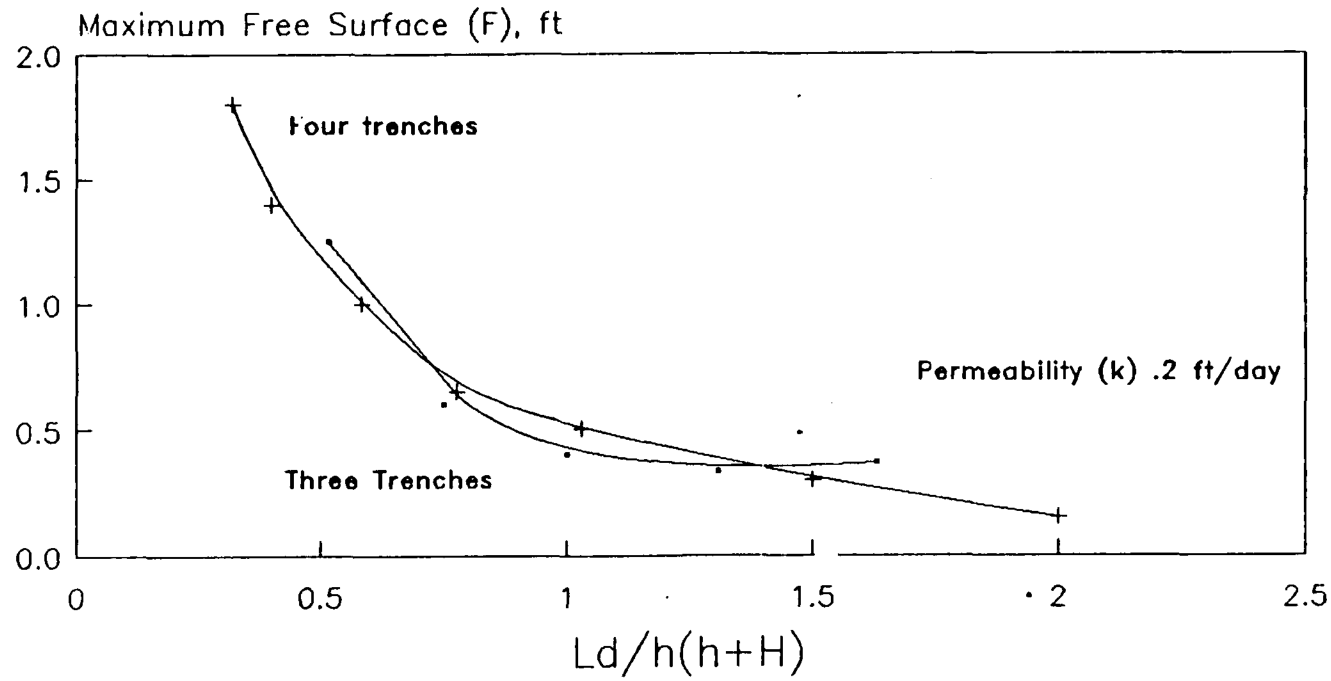

Fig. 4–10
3 & 4 Trenches for maximum free surface
from a dimensionless product

This study has developed an effective method for determining the total flow and maximum free height for a trench drain system, knowing the geometry of the problem. It appears probable that anisotropic conditions, different hydraulic conductivities and trench systems with other then four drains can be included into this type of evaluation with some further research.

V. Comparison of Trench Drain with Blanket Drain:

An alternative to the trench drain system for dewatering beneath a foundation is the blanket drain. A blanket drain system is similar to the trench drain system as it is a mass of open graded stone or gravel isolated from the soil by a geosynthetic filter material and has slotted collector pipes to carry water to a sump for removal. It is different in geometry. The blanket drain is a single rectangular cross section which dewaters the surrounding soil to the depth of the bottom of the section. The trench drain uses less gravel by extending the dewatering depth down with narrow trenches extending from a thin base of gravel across the bottom of the foundation (Figure 3-4).

The blanket drain does an excellent job of dewatering beneath a foundation and has the advantage of easier construction. The biggest difference between the two systems in a practical application is the cost. The trench system requires more detailed labor and excavation

while the blanket drain requires more gravel. To do a cost comparison of the two methods a standard foundation size was necessary to determine the excavation, placement and compaction productivity rates. In this study a foundation of 100 feet by 200 feet was used, only for the establishment of unit costs of labor.

The evaluation is done based on a set slab elevation and a predetermined base of trench or blanket drain. That is the blanket drain will have to be thick enough to dewater to the depth of the trench drain without lowering the foundation. A basic cost to this evaluation was the cost of gravel (#57 stone) which goes for \$8.30/ton in the Atlanta area. Labor costs used were \$20/hr for an equipment operator and \$16/hr for a laborer (both rates including overhead and fringes). Productivity values came from the Means estimating guide for 1989. The cost of equipment rentals were approximated from the same guide. The cost of the geosynthetic filter material was estimated as \$0.70/yd^2 from discussions with suppliers and engineers in the Atlanta area.

The cost data was input into a spreadsheet with a variety of possible trench drain configurations. The costs were calculated for both the trench drain and an equivalent blanket drain for several different systems each with more drains. Table 4-2 is a copy of one such trial. With the cost of gravel so much higher then the

filter material the ratio of trench drain cost to blanket drain cost was less then one in all cases.

With a blanket drain at a shallow elevation the cost comparison is more likely to recommend a blanket drain system. Figure 4-11 is a summary of such a comparison. To use a thickened blanket drain will sacrifice drawdown capacity in exchange for some construction ease and cost benefits. The decision will depend on the application.

TABLE 4-2

Trench and Blanket Drain Costs

Excavation unit costs		Material costs (in place)	
Trench	0.4 $/cu.ft	Geosyn	0.08 $/sq.ft
Blanket	0.08 $/cu.ft	Gravel Tr	0.45 $/cu.ft
		Gravel Bl	0.9 $/cu.ft

Spacing	Trench Width	Trench Depth	Number of Trenches	per unit lngth Trench Total $	Blanket Total $
15	1.5	1	30	38.25	508.96
15	1.5	4	30	153	1920.64
15	2.5	1	30	63.75	540.76
15	2.5	4	30	255	2040.64
25	1.5	1	30	38.25	816.36
25	1.5	4	30	153	3080.64
25	2.5	1	30	63.75	848.16
25	2.5	4	30	255	3200.64
35	1.5	1	30	38.25	1123.76
35	1.5	4	30	153	4240.64
35	2.5	1	30	63.75	1155.56
35	2.5	4	30	255	4360.64

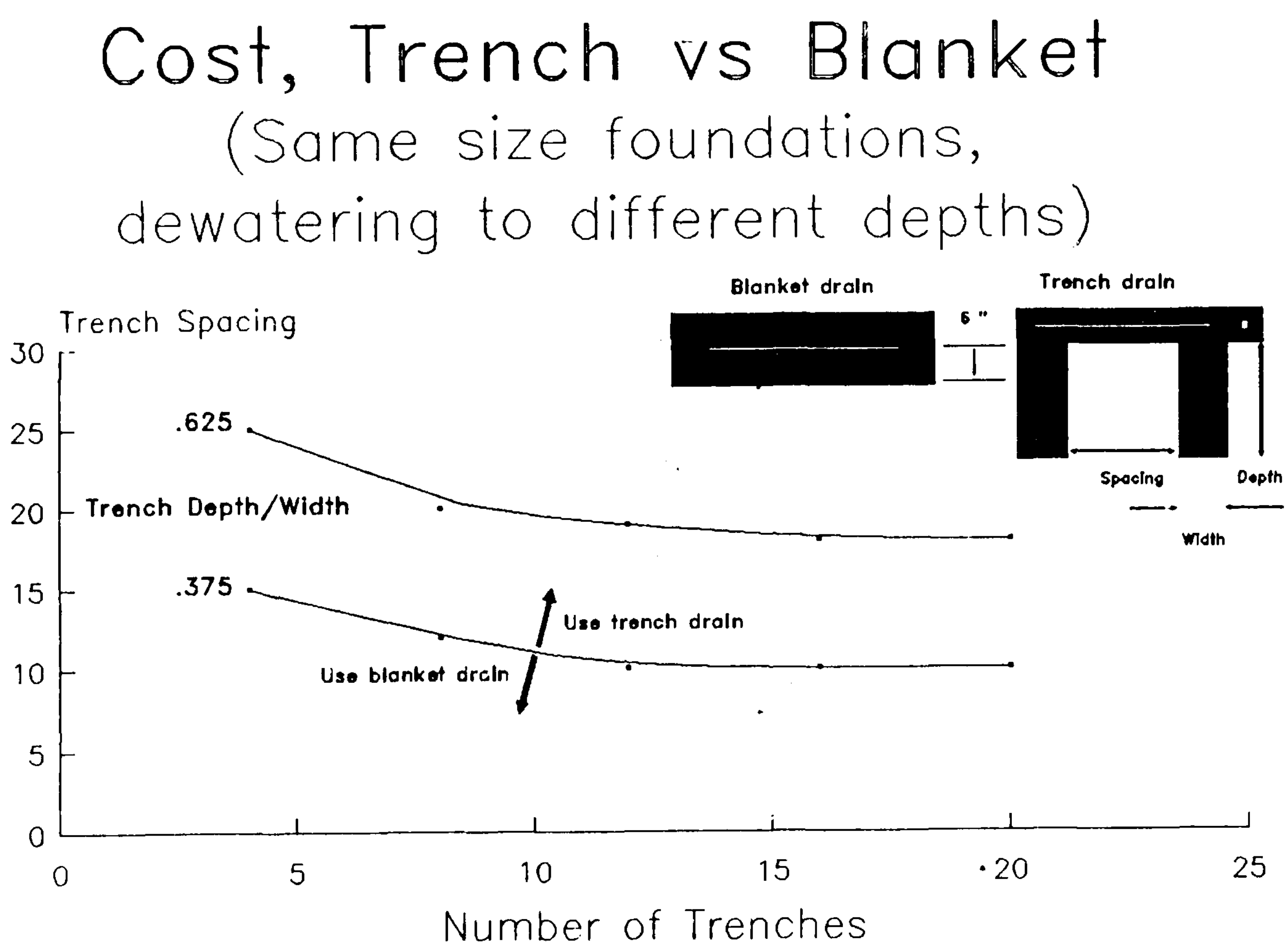

Fig. 4–11
Spacing for ecconomic use of Trench
Drain, dewatering to greater depth

VI. Conclusions:

In this chapter a method for predicting the results of a finite element analysis of a trench drain system for isotropic soil and four drains is presented. A rough approximation has been made to show the possible impact of anisotropy and different trench configurations. Empirical data is not available to validate or modify the predictions of the Aral Seepage Program for a trench drain system. Compared with other slot drain solutions it appears that the finite element solution predicts lesser flows and is so less conservative.

The use of a trench drain system can be justified economically over a blanket drain system in some configurations. The brief evaluation of this chapter provides a simple comparison method for the relative cost differences of the two systems.

CHAPTER 5

CONCLUSIONS

I. Introduction:

In this study the trench drain system was evaluated for thirty six configurations using a finite element analysis program. The results of the analysis were used under dimensional analysis to form a method of predicting the results of a similar analysis for any configuration of a trench drain system within the limits of the study. The final portion of the study was to evaluated the cost of a trench drain system as compared with the blanket drain system for use in a drain beneath a foundation.

II. Trench Drain System Analysis:

The results of the finite element analysis could not be validated by test or field data nor, did the formulas available show close agreement with the results of the analysis. It would be useful if the actual outflow of a trench drain system were measured and the radius of influence of drawdown determined.

This study was limited to isotropic conditions and a four drain system. The affect of other conditions was briefly explored but, a more complete study is necessary before the results are extrapolated to conditions of many drains or variable soils. Initial expectations are that results of Figures 4-7 through 4-10 will be consistent with results of a more complete run of

variables. Whether more then four drains have significantly different shape then the four and three drain curves will be most important when the cost comparison of trench and blanket drains is considered from Figure 4-11.

The one recurring constant in the reference material on dewatering is the variable nature of the radius of influence. For the narrow conditions evaluated in this study reasonable estimations of the radius of influence are possible from Figures 4-1 through 4-3. The earlier recommendations of field observations and computer modeling with other ranges of variables would expand the information available for predicting the radius of influence.

The permeability used in this study, 0.2 ft/day is consistent with the soil in the Atlanta area. If the trench drain system is to be used in a greatly more permeable soil the results may be significantly different. It would not be recommended to use a trench drain in a very porous sand or gravel just as an open sump is not satisfactory to dewater a site of that composition. Establishing the upper and lower bounds of permeability for practical use of trench drains is a most useful recommendation for further study.

III. <u>Predictive Method:</u>

The predictive method using Figures 4-1 through 4-6 work well in predicting the results of the finite element analysis. The forms are easy to use and adapt readily to drain configurations within the range evaluated. The range of variables were selected

to match the conditions under which a trench drain system is normally used. Extrapolation of the results beyond these values may be of limited practicality and questionable accuracy.

The prediction of the maximum free surface at a low dimensionless product (Ld/h(h+H)) should be treated with great care. When the product is less then 0.5 the curve rises rapidly and the maximum free surface exceeds 1.25 feet only in this range. The maximum free surface is of concern only when the water level approaches the shallow blanket immediately beneath the slab, approximately one foot for most trench systems. The curve for the maximum free surface was roughly aligned with the 7% slope values at the left end and the 0% slope values on the right. For large aquifer slopes the curve may approach vertical and might be sufficient reason to avoid the use of a trench drain system in such an aquifer.

IV. <u>Cost Comparison:</u>

If the necessary depth of dewatering is to the depth of the trench drain system a blanket drain cannot compete on an economic basis. If a very shallow level of dewatering is required beneath the foundation it would not be practical to install a trench drain system. Trenches of under one foot depth would require individual consideration. By the results of Figure 4-11 it is apparent that even sacrificing the depth of dewatering is not sufficient to turn the advantage to blanket drains in all cases.

V. Evaluation:

The results of this study have satisfied the stated intentions. Results and input were reviewed with care and show consistent and reasonable trends. Appendix C is a brief description of the method of compilation of data, preparation of data files and execution of program commands. Also included in Appendix D is a storage disk for an IBM compatible computer with the spreadsheets of results and the data files used.

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APPENDIX A

SUMMARY OF PROGRAM COMPUTER RUNS

FINITE ELEMENT COMPUTER RUN SUMMARY

	Spacing	Trench Elevation	Free Head	Radius of Influence	Total Flow	Max Free Surface	Number of Trials
Slope = 0%							
	15	20	10	400	0.11	0.18	6
	15	20	20	550	0.2	0.33	6
	15	60	10	500	0.17	0.35	6
	15	60	20	600	0.29	0.615	6
	25	20	10	400	0.1	0.204	5
	25	20	20	550	0.17	0.35	5
	25	60	10	500	0.15	0.429	5
	25	60	20	600	0.27	0.763	5
	35	20	10	400	0.09	0.227	5
	35	20	20	550	0.15	0.38	5
	35	60	10	500	0.14	0.475	5
	35	60	20	600	0.25	0.853	5
Slope = 3.5%							
	15	20	10	300	0.14	0.38	4
	15	20	20	500	0.19	0.52	4
	15	60	10	450	0.15	0.53	4
	15	60	20	550	0.26	0.93	4
	25	20	10	250	0.14	0.5	4
	25	20	20	450	0.18	0.69	4
	25	60	10	400	0.16	0.79	4
	25	60	20	550	0.24	1.27	4
	35	20	10	200	0.15	0.66	4
	35	20	20	400	0.18	0.82	4
	35	60	10	350	0.18	1.02	4
	35	60	20	500	0.25	1.35	4
Slope = 7%							
	15	20	10	200	0.23	0.6	5
	15	20	20	350	0.3	0.82	5
	15	60	10	300	0.23	0.819	5
	15	60	20	500	0.29	1.016	5
	25	20	10	150	0.27	0.85	5
	25	20	20	250	0.32	1.17	5
	25	60	10	200	0.28	1.27	5
	25	60	20	450	0.31	1.4	5
	35	20	10	100	0.28	1.14	5
	35	20	20	200	0.33	1.432	5
	35	60	10	150	0.33	1.69	5
	35	60	20	400	0.34	1.85	5

Table A-1 Summary of Finite Element Runs

TABLE A-2

SPECIAL PROJECT TEST RUNS FOR ANISOTROPY AND NUMBER OF DRAINS

	Number of Drains	Slope	Trial Radius	Spacing	Trench Elevation	Free Head	k horiz.	k vert.	Total Flow	Max Free Surface	Radius of Influence	Total Flow	Max Free Surface
S8	4	3.5	100	25	60	10	0.2	0.02	0.1202	0.7863			
	4	3.5	300	25	60	10	0.2	0.02	0.0533	0.4095	350	0.08	0.6
	4	3.5	500	25	60	20	0.2	0.02	0.0492	0.347			
S9	4	3.5	200	25	60	10	0.6	0.2	0.3166	0.8284			
	4	3.5	400	25	60	10	0.6	0.2	0.2185	0.5862	350	0.23	0.63
	4	3.5	600	25	60	10	0.6	0.2	0.2026	0.4979			
S10	4	3.5	100	15	20	10	1.23	0.123	0.4001	0.2369			
	4	3.5	300	15	20	10	1.23	0.123	0.1693	0.1253	275	0.18	0.13
	4	3.5	500	15	20	10	1.23	0.123	0.1625	0.1024			
S11	4	3.5	100	15	20	10	0.2	0.02	0.0651	0.2369			
	4	3.5	300	15	20	10	0.2	0.02	0.0276	0.1253	275	0.03	0.13
	4	3.5	500	15	20	10	0.2	0.02	0.0265	0.1024			
S12	4	3.5	100	15	20	10	0.104	0.034	0.0639	0.4493			
	4	3.5	300	15	20	10	0.104	0.034	0.0256	0.2425	275	0.03	0.25
	4	3.5	500	15	20	10	0.104	0.034	0.0238	0.1981			
S13	4	3.5	100	15	20	10	0.6	0.[illegible]	0.3723	0.4531			
	4	3.5	300	15	20	10	0.6	0.2	0.15	0.2447	250	0.17	0.27
	4	3.5	500	15	20	10	0.6	0.2	0.1388	0.1999			
S15	3	3.5	100	15	20	10	0.2	0.2	0.3425	0.7908			
	3	3.5	300	15	20	10	0.2	0.2	0.1344	0.389	325	0.13	0.37
	3	3.5	500	15	20	10	0.2	0.2	0.1056	0.2925			
S16	3	0	300	25	20	20	0.2	0.2	0.2894	0.715			
	3	0	500	25	20	20	0.2	0.2	0.1822	0.4537	700	0.13	0.33
	3	0	700	25	20	20	0.2	0.2	0.1322	0.3321			
S17	3	7	100	35	20	20	0.2	0.2	0.5629	2.0473			
	3	7	300	35	20	20	0.2	0.2	0.2713	1.1976	275	0.29	1.25
	3	7	500	35	20	20	0.2	0.2	0.2653	0.9815			

TABLE A-3

SPECIAL PROJECT TEST RUN DATA SUMMARY

Test	Slope	Trial Radius	Spacing	Trench Elevation	Free Head	k horiz.	k vertical	q-total	Free Surf Max	Radius of Influence	Total Flow	Max Free Surface	::Dimensional Analysis Predic ::Radius of Influence	Total Flow	Max Free Surface
S1	5	200	20	40	15	0.2	0.2	0.76485	1.173						
	5	400	20	40	15	0.2	0.2	1.4287	2.1591	450	0.23	0.8	327	0.26	0.96
	5	600	20	40	15	0.2	0.2	0.88464	1.799						
S2	3.5	400	25	40	20	0.2	0.2	1.594[illegible]3	3.1004						
	3.5	600	25	40	20	0.2	0.2	0.2005	0.8691	610	0.205	0.86	493	0.26	0.96
	3.5	800	25	40	20	0.2	0.2	0.3864	0.6093						
S3	0	200	35	30	10	0.2	0.2	0.8212	1.2552						
	0	400	35	30	10	0.2	0.2	0.5464	1.1507	400	0.09	0.24	425	0.13	0.39
	0	600	35	30	10	0.2	0.2	1.0452	2.0982						
S5	3.5	200	15	50	10	0.2	0.2	0.2823	0.7822						
	3.5	400	15	50	10	0.2	0.2	0.1564	0.5351	400	0.16	0.54	410	0.18	0.7
	3.5	600	15	50	20	0.2	0.2	0.128	0.4383						
S6	7	100	25	30	10	0.2	0.2	0.3186	1.247						
	7	300	25	30	10	0.2	0.2	0.2714	0.8359	150	0.3	1.05	160	0.27	1.07
	7	500	25	30	10	0.2	0.2	0.2675	0.743						
S7	7	200	35	50	20	0.2	0.2	0.428	2.3121						
	7	400	35	50	20	0.2	0.2	0.3347	1.7108	350	.35	1.8	350	0.34	1.41
	7	600	35	50	20	0.2	0.2	0.3212	1.4832						

APPENDIX B

SAMPLE INPUT AND OUTPUT

SAMPLE INPUT DATA FILE

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11,-190,36.65,0
18,-114,3.99,1
24,-114,19.99,1
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41,-43.7,17.5295,1
45,-43.7,29.5295,0
52,-19,0.665,1
58,-19,16.665,1
62,-19,27.665,0
69,0,0,1
75,0,16,1
79,0,25,0
86,10,-0.35,1
92,10,16,1
96,10,20,0
103,11.5,-0.4025,1
109,11.5,16,1
113,11.5,20,0
120,16.5,-0.5775,1
126,16.5,16,1
130,16.5,22,0
137,23,-0.805,1
143,23,16,1
147,23,22,0
154,25,-0.875,1
160,25,16,1
164,25,22,0
171,31.5,-1.1025,1
177,31.5,16,1
181,31.5,22,0
188,36.5,-1.2775,1
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256,51.5,-1.8025,1
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279,58,16,1
283,58,22,0
290,63,-2.205,1
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307,64.5,-2.2575,1
313,64.5,16,1
317,64.5,20,0
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330,69.5,16,1
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347,76,16,1
351,76,22,0
358,78,-2.73,1
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368,78,22,0
375,84.5,-2.9575,1
381,84.5,16,1
385,84.5,22,0
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398,89.5,16,1
402,89.5,20,0
409,91,-3.185,1
415,91,16,1
419,91,20,0
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432,101,15.65,1
436,101,21.465,0
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453,120,21.8,0
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466,144.7,14.1205,1
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504,291,19.815,0
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35,46,52,53,54,47,37,36,4,0.2,0.2,0
52,63,69,70,71,64,54,53,4,0.2,0.2,0
69,80,86,87,88,81,71,70,4,0.2,0.2,0
86,97,103,104,105,98,88,87,4,0.2,0.2,0
103,114,120,121,122,115,105,104,4,0.2,0.2,0
120,131,137,138,139,132,122,121,4,0.2,0.2,0
137,148,154,155,156,149,139,138,4,0.2,0.2,0
154,165,171,172,173,166,156,155,4,0.2,0.2,0
171,182,188,189,190,183,173,172,4,0.2,0.2,0
188,199,205,206,207,200,190,189,4,0.2,0.2,0
205,216,222,223,224,217,207,206,4,0.2,0.2,0
222,233,239,240,241,234,224,223,4,0.2,0.2,0
239,250,256,257,258,251,241,240,4,0.2,0.2,0
256,267,273,274,275,268,258,257,4,0.2,0.2,0
273,284,290,291,292,285,275,274,4,0.2,0.2,0
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290,301,307,308,309,302,292,291,4,0.2,0.2,0
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324,335,341,342,343,336,326,325,4,0.2,0.2,0
341,352,358,359,360,353,343,342,4,0.2,0.2,0
358,369,375,376,377,370,360,359,4,0.2,0.2,0
375,386,392,393,394,387,377,376,4,0.2,0.2,0
392,403,409,410,411,404,394,393,4,0.2,0.2,0
409,420,426,427,428,421,411,410,4,0.2,0.2,0
426,437,443,444,445,438,428,427,4,0.2,0.2,0
443,454,460,461,462,455,445,444,4,0.2,0.2,0
460,471,477,478,479,472,462,461,4,0.2,0.2,0
477,488,494,495,496,489,479,478,4,0.2,0.2,0
1,36.65,5,2,1
96,20,1,17,6
198,20,1,17,6
300,20,1,17,6
402,20,1,17,6
494,19.815,5,2,1
11,7,28,24,45,41,62,58,79,75,96,92,113,109,130,126
147,143,164,160,181,177,198,194,215,211,232,228,249,245,266,262
283,279,300,296,317,313,334,330,351,347,368,364,385,381,402,398
419,415,436,432,453,449,470,466,487,483,504,500
17,34,51,68,85,102,119,136,153,170,187,204,221,238,255,272
289,306,323,340,357,374,391,408,425,442,459,476,493
96,1,17
198,1,17
300,1,17
402,1,17
"End of Problem"
3,0.0001
```

A35521

CE504CW

Userid: CE504CW
File: CE504CW OUTPUT

F - .5902

1 .105
2 .0349
3 .0107
4 .0026

USERID	CE504CW	
ORIGIN	RSCS	
DISTCODE	CE504CW	
SYSTEM	GITVM1	
SPOOLID	8001	
RECORDS	00001063	
FILE	CE504CW	OUTPUT
CREATED	07/03/89	23:02:08
PRINTED	07/03/89	23:02:23
CLASS	A	
FORMS	XD	
DEVICE	600	
SEQUENCE	769	

NUMBER : 4 FERK : 00001

NNPC = 50 NELEMC = 23 NPBDC = 0 NP** = 30 ITGIV = 20 NPBDC = 8 NSPFAC = 4 ITIME = 0

GENERATED NODAL POINT DATA AND (X)-(Y) COORDINATES

NODE	1	X=	-190.0000	Y=	6.6500
NODE	3	X=	-190.0000	Y=	11.9833
NODE	5	X=	-190.0000	Y=	17.3167
NODE	7	X=	-190.0000	Y=	22.6500
NODE	9	X=	-190.0000	Y=	28.6500
NODE	11	X=	-190.0000	Y=	36.6500
NODE	18	X=	-114.0000	Y=	3.8000
NODE	20	X=	-114.0000	Y=	9.3233
NODE	22	X=	-114.0000	Y=	14.8467
NODE	24	X=	-114.0000	Y=	19.9800
NODE	26	X=	-114.0000	Y=	26.4900
NODE	28	X=	-114.0000	Y=	32.9800
NODE	35	X=	-43.7000	Y=	1.5265
NODE	37	X=	-43.7000	Y=	6.8626
NODE	39	X=	-43.7000	Y=	12.1862
NODE	41	X=	-43.7000	Y=	17.5265
NODE	43	X=	-43.7000	Y=	23.5265
NODE	45	X=	-43.7000	Y=	29.5265
NODE	52	X=	-18.0000	Y=	.6650
NODE	54	X=	-18.0000	Y=	5.9983
NODE	56	X=	-18.0000	Y=	11.3317
NODE	58	X=	-18.0000	Y=	16.6650
NODE	60	X=	-18.0000	Y=	22.1650
NODE	62	X=	-18.0000	Y=	27.6650
NODE	69	X=	0.0000	Y=	0.0000
NODE	71	X=	0.0000	Y=	5.3333
NODE	73	X=	0.0000	Y=	10.6667
NODE	75	X=	0.0000	Y=	16.0000
NODE	77	X=	0.0000	Y=	20.5000
NODE	79	X=	0.0000	Y=	25.0000
NODE	86	X=	10.0000	Y=	-.3500
NODE	88	X=	10.0000	Y=	5.1000
NODE	90	X=	10.0000	Y=	10.5500
NODE	92	X=	10.0000	Y=	16.0000
NODE	94	X=	10.0000	Y=	18.0000
NODE	96	X=	10.0000	Y=	20.0000
NODE	103	X=	11.5000	Y=	-.4025
NODE	105	X=	11.5000	Y=	5.0650
NODE	107	X=	11.5000	Y=	10.5325
NODE	109	X=	11.5000	Y=	16.0000
NODE	111	X=	11.5000	Y=	18.0000
NODE	113	X=	11.5000	Y=	20.0000
NODE	120	X=	16.5000	Y=	-.5775
NODE	122	X=	16.5000	Y=	4.9483
NODE	124	X=	16.5000	Y=	10.4742
NODE	126	X=	16.5000	Y=	16.0000
NODE	128	X=	16.5000	Y=	19.0000
NODE	130	X=	16.5000	Y=	22.0000
NODE	137	X=	23.0000	Y=	-.8050
NODE	139	X=	23.0000	Y=	4.7967
NODE	141	X=	23.0000	Y=	10.3983
NODE	143	X=	23.0000	Y=	16.0000
NODE	145	X=	23.0000	Y=	19.0000
NODE	147	X=	23.0000	Y=	22.0000
NODE	154	X=	25.0000	Y=	-.8750
NODE	156	X=	25.0000	Y=	4.7500
NODE	158	X=	25.0000	Y=	10.3750
NODE	160	X=	25.0000	Y=	16.0000
NODE	162	X=	25.0000	Y=	19.0000
NODE	164	X=	25.0000	Y=	22.0000
NODE	171	X=	31.5000	Y=	-1.1025
NODE	173	X=	31.5000	Y=	4.5983
NODE	175	X=	31.5000	Y=	10.2992
NODE	177	X=	31.5000	Y=	16.0000
NODE	179	X=	31.5000	Y=	19.0000
NODE	181	X=	31.5000	Y=	22.0000
NODE	188	X=	36.5000	Y=	-1.2775
NODE	190	X=	36.5000	Y=	4.4817
NODE	192	X=	36.5000	Y=	10.2408
NODE	194	X=	36.5000	Y=	16.0000
NODE	196	X=	36.5000	Y=	18.0000
NODE	198	X=	36.5000	Y=	20.0000
NODE	205	X=	38.0000	Y=	-1.3300
NODE	207	X=	38.0000	Y=	4.4467
NODE	209	X=	38.0000	Y=	10.2233
NODE	211	X=	38.0000	Y=	16.0000
NODE	213	X=	38.0000	Y=	18.0000
NODE	215	X=	38.0000	Y=	20.0000
NODE	222	X=	43.0000	Y=	-1.5050
NODE	224	X=	43.0000	Y=	4.3300
NODE	226	X=	43.0000	Y=	10.1650
NODE	228	X=	43.0000	Y=	16.0000
NODE	230	X=	43.0000	Y=	19.0000
NODE	232	X=	43.0000	Y=	22.0000
NODE	239	X=	48.5000	Y=	-1.7325
NODE	241	X=	48.5000	Y=	4.1783
NODE	243	X=	48.5000	Y=	10.0892
NODE	245	X=	48.5000	Y=	16.0000
NODE	247	X=	48.5000	Y=	19.0000
NODE	249	X=	48.5000	Y=	22.0000
NODE	256	X=	51.5000	Y=	-1.8025
NODE	258	X=	51.5000	Y=	4.1317
NODE	260	X=	51.5000	Y=	10.0658
NODE	262	X=	51.5000	Y=	16.0000
NODE	264	X=	51.5000	Y=	19.0000
NODE	266	X=	51.5000	Y=	22.0000
NODE	273	X=	58.0000	Y=	-2.0300
NODE	275	X=	58.0000	Y=	3.9800
NODE	277	X=	58.0000	Y=	9.9900
NODE	279	X=	58.0000	Y=	16.0000
NODE	281	X=	58.0000	Y=	19.0000
NODE	283	X=	58.0000	Y=	22.0000
NODE	290	X=	63.0000	Y=	-2.2050
NODE	292	X=	63.0000	Y=	3.8633
NODE	294	X=	63.0000	Y=	9.9317
NODE	296	X=	63.0000	Y=	16.0000
NODE	298	X=	63.0000	Y=	18.0000
NODE	300	X=	63.0000	Y=	20.0000
NODE	307	X=	64.5000	Y=	-2.2575
NODE	309	X=	64.5000	Y=	3.8283
NODE	311	X=	64.5000	Y=	9.9142
NODE	313	X=	64.5000	Y=	16.0000
NODE	315	X=	64.5000	Y=	18.0000
NODE	317	X=	64.5000	Y=	20.0000
NODE	324	X=	69.5000	Y=	-2.4325
NODE	326	X=	69.5000	Y=	3.7117
NODE	328	X=	69.5000	Y=	9.8558
NODE	330	X=	69.5000	Y=	16.0000
NODE	332	X=	69.5000	Y=	19.0000
NODE	334	X=	69.5000	Y=	22.0000
NODE	341	X=	76.0000	Y=	-2.6600

NODE 351	X= 78.0000	Y= 22.0000
NODE 358	X= 76.0000	Y= -2.7300
NODE 360	X= 78.0000	Y= 3.5133
NODE 362	X= 78.0000	Y= 9.7567
NODE 364	X= 78.0000	Y= 16.0000
NODE 366	X= 78.0000	Y= 19.0000
NODE 368	X= 78.0000	Y= 22.0000
NODE 375	X= 84.5000	Y= -2.8575
NODE 377	X= 84.5000	Y= 3.3817
NODE 379	X= 84.5000	Y= 9.5808
NODE 381	X= 84.5000	Y= 16.0000
NODE 383	X= 84.5000	Y= 19.0000
NODE 385	X= 84.5000	Y= 22.0000
NODE 392	X= 89.5000	Y= -3.1325
NODE 394	X= 89.5000	Y= 3.2450
NODE 396	X= 89.5000	Y= 9.6225
NODE 398	X= 89.5000	Y= 16.0000
NODE 400	X= 89.5000	Y= 18.0000
NODE 402	X= 89.5000	Y= 20.0000
NODE 409	X= 91.0000	Y= -3.1850
NODE 411	X= 91.0000	Y= 3.2100
NODE 413	X= 91.0000	Y= 9.6050
NODE 415	X= 91.0000	Y= 16.0000
NODE 417	X= 91.0000	Y= 18.0000
NODE 419	X= 91.0000	Y= 20.0000
NODE 426	X= 101.0000	Y= -3.5350
NODE 428	X= 101.0000	Y= 2.8600
NODE 430	X= 101.0000	Y= 9.2550
NODE 432	X= 101.0000	Y= 15.6500
NODE 434	X= 101.0000	Y= 18.5575
NODE 436	X= 101.0000	Y= 21.4650
NODE 443	X= 120.0000	Y= -4.2000
NODE 445	X= 120.0000	Y= 2.1950
NODE 447	X= 120.0000	Y= 8.5900
NODE 449	X= 120.0000	Y= 14.9850
NODE 451	X= 120.0000	Y= 18.3925
NODE 453	X= 120.0000	Y= 21.8000
NODE 460	X= 144.7000	Y= -5.0645
NODE 462	X= 144.7000	Y= 1.3305
NODE 464	X= 144.7000	Y= 7.7255
NODE 466	X= 144.7000	Y= 14.1205
NODE 468	X= 144.7000	Y= 18.5280
NODE 470	X= 144.7000	Y= 22.9355
NODE 477	X= 215.0000	Y= -7.5250
NODE 479	X= 215.0000	Y= -1.1300
NODE 481	X= 215.0000	Y= 5.2850
NODE 483	X= 215.0000	Y= 11.6800
NODE 485	X= 215.0000	Y= 16.5575
NODE 487	X= 215.0000	Y= 21.4750
NODE 494	X= 291.0000	Y= -10.1650
NODE 496	X= 291.0000	Y= -3.7900
NODE 498	X= 291.0000	Y= 2.6050
NODE 500	X= 291.0000	Y= 9.0000
NODE 502	X= 291.0000	Y= 14.4075
NODE 504	X= 291.0000	Y= 19.8150

NUMBER OF NODAL POINTS... 504

NUMBER OF ELEMENTS....... 145

ELE. NO. NODAL POINTS

1	1	12	18	19	20	13	3	2	.20000E+00	.20000E+00	0.
2	3	13	20	21	22	14	5	4	.20000E+00	.20000E+00	0.
3	5	14	22	23	24	15	7	6	.20000E+00	.20000E+00	0.
4	7	15	24	25	26	16	9	8	.20000E+00	.20000E+00	0.
5	9	16	26	27	28	17	11	10	.20000E+00	.20000E+00	0.
6	18	29	35	36	37	30	20	19	.20000E+00	.20000E+00	0.
7	20	30	37	38	39	31	22	21	.20000E+00	.20000E+00	0.
8	22	31	39	40	41	32	24	23	.20000E+00	.20000E+00	0.
9	24	32	41	42	43	33	26	25	.20000E+00	.20000E+00	0.
10	26	33	43	44	45	34	28	27	.20000E+00	.20000E+00	0.
11	35	46	52	53	54	47	37	36	.20000E+00	.20000E+00	0.
12	37	47	54	55	56	48	39	38	.20000E+00	.20000E+00	0.
13	39	48	56	57	58	49	41	40	.20000E+00	.20000E+00	0.
14	41	49	58	59	60	50	43	42	.20000E+00	.20000E+00	0.
15	43	50	60	61	62	51	45	44	.20000E+00	.20000E+00	0.
16	52	63	69	70	71	64	54	53	.20000E+00	.20000E+00	0.
17	54	64	71	72	73	65	56	55	.20000E+00	.20000E+00	0.
18	56	65	73	74	75	66	58	57	.20000E+00	.20000E+00	0.
19	58	66	75	76	77	67	60	59	.20000E+00	.20000E+00	0.
20	60	67	77	78	79	68	62	61	.20000E+00	.20000E+00	0.
21	69	80	86	87	88	81	71	70	.20000E+00	.20000E+00	0.
22	71	81	88	89	90	82	73	72	.20000E+00	.20000E+00	0.
23	73	82	90	91	92	83	75	74	.20000E+00	.20000E+00	0.
24	75	83	92	93	94	84	77	76	.20000E+00	.20000E+00	0.
25	77	84	94	95	96	85	79	78	.20000E+00	.20000E+00	0.
26	86	97	103	104	105	98	88	87	.20000E+00	.20000E+00	0.
27	88	98	105	106	107	99	90	89	.20000E+00	.20000E+00	0.
28	90	99	107	108	109	100	92	91	.20000E+00	.20000E+00	0.
29	92	100	109	110	111	101	94	93	.20000E+00	.20000E+00	0.
30	94	101	111	112	113	102	96	95	.20000E+00	.20000E+00	0.
31	103	114	120	121	122	115	105	104	.20000E+00	.20000E+00	0.
32	105	115	122	123	124	116	107	106	.20000E+00	.20000E+00	0.
33	107	116	124	125	126	117	109	108	.20000E+00	.20000E+00	0.
34	109	117	126	127	128	118	111	110	.20000E+00	.20000E+00	0.
35	111	118	128	129	130	119	113	112	.20000E+00	.20000E+00	0.
36	120	131	137	138	139	132	122	121	.20000E+00	.20000E+00	0.
37	122	132	139	140	141	133	124	123	.20000E+00	.20000E+00	0.
38	124	133	141	142	143	134	126	125	.20000E+00	.20000E+00	0.
39	126	134	143	144	145	135	128	127	.20000E+00	.20000E+00	0.
40	128	135	145	146	147	136	130	129	.20000E+00	.20000E+00	0.
41	137	148	154	155	156	149	139	138	.20000E+00	.20000E+00	0.
42	139	149	156	157	158	150	141	140	.20000E+00	.20000E+00	0.
43	141	150	158	159	160	151	143	142	.20000E+00	.20000E+00	0.
44	143	151	160	161	162	152	145	144	.20000E+00	.20000E+00	0.
45	145	152	162	163	164	153	147	146	.20000E+00	.20000E+00	0.
46	154	165	171	172	173	166	156	155	.20000E+00	.20000E+00	0.
47	156	166	173	174	175	167	158	157	.20000E+00	.20000E+00	0.
48	158	167	175	176	177	168	160	159	.20000E+00	.20000E+00	0.
49	160	168	177	178	179	169	162	161	.20000E+00	.20000E+00	0.
50	162	169	179	180	181	170	164	163	.20000E+00	.20000E+00	0.
51	171	182	188	189	190	183	173	172	.20000E+00	.20000E+00	0.
52	173	183	190	191	192	184	175	174	.20000E+00	.20000E+00	0.
53	175	184	192	193	194	185	177	176	.20000E+00	.20000E+00	0.
54	177	185	194	195	196	186	179	178	.20000E+00	.20000E+00	0.
55	179	186	196	197	198	187	181	180	.20000E+00	.20000E+00	0.
56	188	199	205	206	207	200	190	189	.20000E+00	.20000E+00	0.
57	190	200	207	208	209	201	192	191	.20000E+00	.20000E+00	0.
58	192	201	209	210	211	202	194	193	.20000E+00	.20000E+00	0.
59	194	202	211	212	213	203	196	195	.20000E+00	.20000E+00	0.
60	196	203	213	214	215	204	198	197	.20000E+00	.20000E+00	0.
61	205	216	222	223	224	217	207	206	.20000E+00	.20000E+00	0.
62	207	217	224	225	226	218	209	208	.20000E+00	.20000E+00	0.
63	209	218	226	227	228	219	211	210	.20000E+00	.20000E+00	0.
64	211	219	228	229	230	220	213	212	.20000E+00	.20000E+00	0.
65	213	220	230	231	232	221	215	214	.20000E+00	.20000E+00	0.
66	222	233	239	240	241	234	224	223	.20000E+00	.20000E+00	0.
67	224	234	241	242	243	235	226	225	.20000E+00	.20000E+00	0

71	239	250	256	257	258	251	241	240	.20000E+00	.20000E+00	0.
72	241	251	258	259	260	252	243	242	.20000E+00	.20000E+00	0.
73	243	252	260	261	262	253	245	244	.20000E+00	.20000E+00	0.
74	245	253	262	263	264	254	247	246	.20000E+00	.20000E+00	0.
75	247	254	264	265	266	255	249	248	.20000E+00	.20000E+00	0.
76	256	267	273	274	275	268	258	257	.20000E+00	.20000E+00	0.
77	258	268	275	276	277	269	260	259	.20000E+00	.20000E+00	0.
78	260	269	277	278	279	270	262	261	.20000E+00	.20000E+00	0.
79	262	270	279	280	281	271	264	263	.20000E+00	.20000E+00	0.
80	264	271	281	282	283	272	266	265	.20000E+00	.20000E+00	0.
81	273	284	290	291	292	285	275	274	.20000E+00	.20000E+00	0
82	275	285	292	293	294	286	277	276	.20000E+00	.20000E+00	0.
83	277	286	294	295	296	287	279	278	.20000E+00	.20000E+00	0.
84	279	287	296	297	298	288	281	280	.20000E+00	.20000E+00	0.
85	281	288	298	299	300	289	283	282	.20000E+00	.20000E+00	0.
86	290	301	307	308	309	302	292	291	.20000E+00	.20000E+00	0.
87	292	302	309	310	311	303	294	293	.20000E+00	.20000E+00	0.
88	294	303	311	312	313	304	296	295	.20000E+00	.20000E+00	0.
89	296	304	313	314	315	305	298	297	.20000E+00	.20000E+00	0.
90	298	305	315	316	317	306	300	299	.20000E+00	.20000E+00	0.
91	307	318	324	325	326	319	309	308	.20000E+00	.20000E+00	0.
92	309	319	326	327	328	320	311	310	.20000E+00	.20000E+00	0.
93	311	320	328	329	330	321	313	312	.20000E+00	.20000E+00	0.
94	313	321	330	331	332	322	315	314	.20000E+00	.20000E+00	0.
95	315	322	332	333	334	323	317	316	.20000E+00	.20000E+00	0.
96	324	335	341	342	343	336	326	325	.20000E+00	.20000E+00	0.
97	326	336	343	344	345	337	328	327	.20000E+00	.20000E+00	0.
98	328	337	345	346	347	338	330	329	.20000E+00	.20000E+00	0.
99	330	338	347	348	349	339	332	331	.20000E+00	.20000E+00	0.
100	332	339	349	350	351	340	334	333	.20000E+00	.20000E+00	0.
101	341	352	358	359	360	353	343	342	.20000E+00	.20000E+00	0.
102	343	353	360	361	362	354	345	344	.20000E+00	.20000E+00	0.
103	345	354	362	363	364	355	347	346	.20000E+00	.20000E+00	0.
104	347	355	364	365	366	356	349	348	.20000E+00	.20000E+00	0.
105	349	356	366	367	368	357	351	350	.20000E+00	.20000E+00	0.
106	358	369	375	376	377	370	360	359	.20000E+00	.20000E+00	0.
107	360	370	377	378	379	371	362	361	.20000E+00	.20000E+00	0.
108	362	371	379	380	381	372	364	363	.20000E+00	.20000E+00	0.
109	364	372	381	382	383	373	366	365	.20000E+00	.20000E+00	0.
110	366	373	383	384	385	374	368	367	.20000E+00	.20000E+00	0.
111	375	386	392	393	394	387	377	376	.20000E+00	.20000E+00	0.
112	377	387	394	395	396	388	379	378	.20000E+00	.20000E+00	0.
113	379	388	396	397	398	389	381	380	.20000E+00	.20000E+00	0.
114	381	389	398	399	400	390	383	382	.20000E+00	.20000E+00	0.
115	383	390	400	401	402	391	385	384	.20000E+00	.20000E+00	0.
116	392	403	409	410	411	404	394	393	.20000E+00	.20000E+00	0.
117	394	404	411	412	413	405	396	395	.20000E+00	.20000E+00	0.
118	396	405	413	414	415	406	398	397	.20000E+00	.20000E+00	0.
119	398	406	415	416	417	407	400	399	.20000E+00	.20000E+00	0.
120	400	407	417	418	419	408	402	401	.20000E+00	.20000E+00	0.
121	409	420	426	427	428	421	411	410	.20000E+00	.20000E+00	0.
122	411	421	428	429	430	422	413	412	.20000E+00	.20000E+00	0.
123	413	422	430	431	432	423	415	414	.20000E+00	.20000E+00	0.
124	415	423	432	433	434	424	417	416	.20000E+00	.20000E+00	0.
125	417	424	434	435	436	425	419	418	.20000E+00	.20000E+00	0.
126	426	437	443	444	445	438	428	427	.20000E+00	.20000E+00	0.
127	428	438	445	446	447	439	430	429	.20000E+00	.20000E+00	0.
128	430	439	447	448	449	440	432	431	.20000E+00	.20000E+00	0.
129	432	440	449	450	451	441	434	433	.20000E+00	.20000E+00	0.
130	434	441	451	452	453	442	436	435	.20000E+00	.20000E+00	0.
131	443	454	460	461	462	455	445	444	.20000E+00	.20000E+00	0.
132	445	455	462	463	464	456	447	446	.20000E+00	.20000E+00	0.
133	447	456	464	465	466	457	449	448	.20000E+00	.20000E+00	0.
134	449	457	466	467	468	458	451	450	.20000E+00	.20000E+00	0.
135	451	458	468	469	470	459	453	452	.20000E+00	.20000E+00	0.
136	460	471	477	478	479	472	462	461	.20000E+00	.20000E+00	0.
137	462	472	479	480	481	473	464	463	.20000E+00	.20000E+00	0.
138	464	473	481	482	483	474	466	465	.20000E+00	.20000E+00	0.
139	466	474	483	484	485	475	468	467	.20000E+00	.20000E+00	0.
140	468	475	485	486	487	476	470	469	.20000E+00	.20000E+00	0.
141	477	488	494	495	496	489	479	478	.20000E+00	.20000E+00	0.
142	479	489	496	497	498	490	481	480	.20000E+00	.20000E+00	0.
143	481	490	498	499	500	491	483	482	.20000E+00	.20000E+00	0.
144	483	491	500	501	502	492	485	484	.20000E+00	.20000E+00	0.
145	485	492	502	503	504	493	487	486	.20000E+00	.20000E+00	0.

DIRICHLET BOUNDARY CONDITION DATA

ONODES	RESPECTIVE DIRICHLET BOUNDARY CONDITIONS	
, 1- 2	36.6500	36.6500
, 3- 4	36.6500	36.6500
, 5- 6	36.6500	36.6500
, 7- 8	36.6500	36.6500
, 9- 10	36.6500	36.6500
, 11- 10	36.6500	36.6500
, 96-102	20.0000	20.0000
,113-102	20.0000	20.0000
,198-204	20.0000	20.0000
,215-204	20.0000	20.0000
,300-306	20.0000	20.0000
,317-306	20.0000	20.0000
,402-408	20.0000	20.0000
,419-408	20.0000	20.0000
,494-495	19.8150	19.8150
,496-497	19.8150	19.8150
,498-499	19.8150	19.8150
,500-501	19.8150	19.8150
,502-503	19.8150	19.8150
,504-503	19.8150	19.8150

0

NODAL POINTS ON FREE SURFACE

11	17	28	34	45	51	62	68	79	85	96	102	113	119	130	136	147	153	164	170
181	187	198	204	215	221	232	238	249	255	266	272	283	289	300	306	317	323	334	340
351	357	368	374	385	391	402	408	419	425	436	442	453	459	470	476	487	493	504	0

SEEPAGE FACE NODAL POINT DATA

CONSECUTIVE NODE NUMBERS ON THE SEEPAGE FACE

, 96-113
,198-215
,300-317
,402-419

ITER = 1

NEW COORDINATES OF THE FREE SURFACE LINE

NODE=487	X =	215.0000	Y =	19.8889
NODE=470	X =	144.7000	Y =	19.9582
NODE=453	X =	120.0000	Y =	19.9848
NODE=436	X =	101.0000	Y =	20.0034
NODE=419	X =	91.0000	Y =	20.0000
NODE=402	X =	89.5000	Y =	20.0000
NODE=385	X =	84.5000	Y =	20.0281
NODE=368	X =	78.0000	Y =	20.0387

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NODE=300     X =   63.0000     Y =   20.0000
NODE=283     X =   58.0000     Y =   20.0972
NODE=266     X =   51.5000     Y =   20.1395
NODE=249     X =   49.5000     Y =   20.1461
NODE=232     X =   43.0000     Y =   20.1490
NODE=215     X =   38.0000     Y =   20.0000
NODE=198     X =   36.5000     Y =   20.0000
NODE=181     X =   31.5000     Y =   20.3377
NODE=164     X =   25.0000     Y =   20.4657
NODE=147     X =   23.0000     Y =   20.5162
NODE=130     X =   16.5000     Y =   20.5218
NODE=113     X =   11.5000     Y =   20.0000
NODE= 96     X =   10.0000     Y =   20.0000
NODE= 79     X =    0.0000     Y =   22.0338
NODE= 62     X =  -19.0000     Y =   23.8668
NODE= 45     X =  -43.7000     Y =   25.6188
NODE= 28     X = -114.0000     Y =   31.0307
NODE= 11     X = -190.0000     Y =   36.8500

        ITER =    2

    NEW COORDINATES OF THE FREE SURFACE LINE

NODE=487     X =  215.0000     Y =   19.8888
NODE=470     X =  144.7000     Y =   19.9634
NODE=453     X =  120.0000     Y =   19.9910
NODE=436     X =  101.0000     Y =   20.0100
NODE=419     X =   91.0000     Y =   20.0000
NODE=402     X =   89.5000     Y =   20.0000
NODE=385     X =   84.5000     Y =   20.0323
NODE=368     X =   78.0000     Y =   20.0502
NODE=351     X =   76.0000     Y =   20.0539
NODE=334     X =   69.5000     Y =   20.0582
NODE=317     X =   64.5000     Y =   20.0000
NODE=300     X =   63.0000     Y =   20.0000
NODE=283     X =   58.0000     Y =   20.1109
NODE=266     X =   51.5000     Y =   20.1669
NODE=249     X =   49.5000     Y =   20.1780
NODE=232     X =   43.0000     Y =   20.1827
NODE=215     X =   38.0000     Y =   20.0000
NODE=198     X =   36.5000     Y =   20.0000
NODE=181     X =   31.5000     Y =   20.3813
NODE=164     X =   25.0000     Y =   20.5404
NODE=147     X =   23.0000     Y =   20.5757
NODE=130     X =   16.5000     Y =   20.5885
NODE=113     X =   11.5000     Y =   20.0000
NODE= 96     X =   10.0000     Y =   20.0000
NODE= 79     X =    0.0000     Y =   21.9330
NODE= 62     X =  -19.0000     Y =   23.7191
NODE= 45     X =  -43.7000     Y =   25.8305
NODE= 28     X = -114.0000     Y =   31.3538
NODE= 11     X = -190.0000     Y =   36.8500

        ITER =    3

    NEW COORDINATES OF THE FREE SURFACE LINE

NODE=487     X =  215.0000     Y =   19.8888
NODE=470     X =  144.7000     Y =   19.9638
NODE=453     X =  120.0000     Y =   19.9912
NODE=436     X =  101.0000     Y =   20.0102

NODE=419     X =   91.0000     Y =   20.0000
NODE=402     X =   89.5000     Y =   20.0000
NODE=385     X =   84.5000     Y =   20.0325
NODE=368     X =   78.0000     Y =   20.0505
NODE=351     X =   76.0000     Y =   20.0542
NODE=334     X =   69.5000     Y =   20.0585
NODE=317     X =   64.5000     Y =   20.0000
NODE=300     X =   63.0000     Y =   20.0000
NODE=283     X =   58.0000     Y =   20.1118
NODE=266     X =   51.5000     Y =   20.1677
NODE=249     X =   49.5000     Y =   20.1789
NODE=232     X =   43.0000     Y =   20.1834
NODE=215     X =   38.0000     Y =   20.0000
NODE=198     X =   36.5000     Y =   20.0000
NODE=181     X =   31.5000     Y =   20.3837
NODE=164     X =   25.0000     Y =   20.5432
NODE=147     X =   23.0000     Y =   20.5784
NODE=130     X =   16.5000     Y =   20.5902
NODE=113     X =   11.5000     Y =   20.0000
NODE= 96     X =   10.0000     Y =   20.0000
NODE= 79     X =    0.0000     Y =   21.9493
NODE= 62     X =  -19.0000     Y =   23.7517
NODE= 45     X =  -43.7000     Y =   25.8617
NODE= 28     X = -114.0000     Y =   31.3582
NODE= 11     X = -190.0000     Y =   36.8500

        ITER =    4

    NEW COORDINATES OF THE FREE SURFACE LINE

NODE=487     X =  215.0000     Y =   19.8889
NODE=470     X =  144.7000     Y =   19.9638
NODE=453     X =  120.0000     Y =   19.9912
NODE=436     X =  101.0000     Y =   20.0102
NODE=419     X =   91.0000     Y =   20.0000
NODE=402     X =   89.5000     Y =   20.0000
NODE=385     X =   84.5000     Y =   20.0325
NODE=368     X =   78.0000     Y =   20.0505
NODE=351     X =   76.0000     Y =   20.0542
NODE=334     X =   69.5000     Y =   20.0585
NODE=317     X =   64.5000     Y =   20.0000
NODE=300     X =   63.0000     Y =   20.0000
NODE=283     X =   58.0000     Y =   20.1118
NODE=266     X =   51.5000     Y =   20.1677
NODE=249     X =   49.5000     Y =   20.1789
NODE=232     X =   43.0000     Y =   20.1834
NODE=215     X =   38.0000     Y =   20.0000
NODE=198     X =   36.5000     Y =   20.0000
NODE=181     X =   31.5000     Y =   20.3837
NODE=164     X =   25.0000     Y =   20.5432
NODE=147     X =   23.0000     Y =   20.5783
NODE=130     X =   16.5000     Y =   20.5902   <—— F = .5902
NODE=113     X =   11.5000     Y =   20.0000
NODE= 96     X =   10.0000     Y =   20.0000
NODE= 79     X =    0.0000     Y =   21.9500
NODE= 62     X =  -19.0000     Y =   23.7513
NODE= 45     X =  -43.7000     Y =   25.8593
NODE= 28     X = -114.0000     Y =   31.3632
NODE= 11     X = -190.0000     Y =   36.8500

        CONVERGENCE CHECK ERROR =        .3734E-06

ONODE   X COORDINATE   Y COORDINATE   V-POTENTIAL   X-VELOCITY   Y-VELOCITY   TOTAL VELO.   PRES. COEF.
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5	-190.0000	17.3167	36.8500	-.1355E-01	.1099E-03	.1355E-01
6	-190.0000	19.9833	36.8500	-.1348E-01	.7180E-14	.1348E-01
7	-190.0000	22.6500	36.8500	-.1340E-01	.1141E-03	.1340E-01
8	-190.0000	25.1500	36.8500	-.1330E-01	0.	.1330E-01
9	-190.0000	28.6500	36.8500	-.1318E-01	.1368E-03	.1318E-01
10	-190.0000	33.1500	36.8500	-.1307E-01	.1094E-13	.1307E-01
11	-190.0000	36.8500	36.8500	-.1293E-01	.1885E-03	.1294E-01
12	-152.0000	5.3200	33.9980	-.1419E-01	.4429E-03	.1420E-01
13	-152.0000	10.6533	34.0034	-.1415E-01	.5015E-03	.1416E-01
14	-152.0000	15.9867	34.0205	-.1411E-01	.5699E-03	.1412E-01
15	-152.0000	21.3200	34.0398	-.1405E-01	.6458E-03	.1406E-01
16	-152.0000	27.6606	34.0683	-.1397E-01	.7485E-03	.1399E-01
17	-152.0000	34.0018	34.0973	-.1388E-01	.8805E-03	.1391E-01
18	-114.0000	3.9900	31.2516	-.1467E-01	.5174E-03	.1468E-01
19	-114.0000	6.6567	31.2580	-.1468E-01	.5176E-03	.1469E-01
20	-114.0000	9.3233	31.2653	-.1468E-01	.6397E-03	.1469E-01
21	-114.0000	11.9900	31.2735	-.1469E-01	.6440E-03	.1470E-01
22	-114.0000	14.6567	31.2825	-.1469E-01	.7600E-03	.1471E-01
23	-114.0000	17.3233	31.2922	-.1469E-01	.7571E-03	.1471E-01
24	-114.0000	19.9900	31.3027	-.1470E-01	.8728E-03	.1472E-01
25	-114.0000	22.8308	31.3144	-.1471E-01	.8495E-03	.1473E-01
26	-114.0000	25.6716	31.3268	-.1471E-01	.9841E-03	.1474E-01
27	-114.0000	28.5124	31.3397	-.1472E-01	.9279E-03	.1475E-01
28	-114.0000	31.3532	31.3532	-.1472E-01	.1092E-02	.1476E-01
29	-78.8500	2.7598	28.5764	-.1565E-01	.5418E-03	.1566E-01
30	-78.8500	8.0931	28.5929	-.1563E-01	.6789E-03	.1565E-01
31	-78.8500	13.4264	28.6131	-.1562E-01	.8172E-03	.1564E-01
32	-78.8500	18.7598	28.6368	-.1559E-01	.9533E-03	.1562E-01
33	-78.8500	23.6830	28.6621	-.1557E-01	.1076E-02	.1560E-01
34	-78.8500	28.6062	28.6908	-.1554E-01	.1200E-02	.1558E-01
35	-43.7000	1.5295	25.7439	-.1659E-01	.5829E-03	.1660E-01
36	-43.7000	4.1962	25.7520	-.1658E-01	.6663E-03	.1660E-01
37	-43.7000	6.8628	25.7613	-.1658E-01	.7521E-03	.1659E-01
38	-43.7000	9.5295	25.7718	-.1656E-01	.8259E-03	.1658E-01
39	-43.7000	12.1962	25.7834	-.1655E-01	.9212E-03	.1657E-01
40	-43.7000	14.8628	25.7960	-.1653E-01	.9920E-03	.1656E-01
41	-43.7000	17.5295	25.8098	-.1651E-01	.1081E-02	.1655E-01
42	-43.7000	19.6119	25.8213	-.1650E-01	.1134E-02	.1654E-01
43	-43.7000	21.6944	25.8334	-.1649E-01	.1204E-02	.1653E-01
44	-43.7000	23.7768	25.8459	-.1647E-01	.1227E-02	.1652E-01
45	-43.7000	25.8593	25.8590	-.1644E-01	.1327E-02	.1649E-01
46	-31.3500	1.0973	24.7037	-.1701E-01	.5906E-03	.1702E-01
47	-31.3500	6.4306	24.7218	-.1700E-01	.7522E-03	.1702E-01
48	-31.3500	11.7639	24.7447	-.1701E-01	.9292E-03	.1703E-01
49	-31.3500	17.0973	24.7725	-.1700E-01	.1133E-02	.1704E-01
50	-31.3500	20.9513	24.7959	-.1697E-01	.1274E-02	.1702E-01
51	-31.3500	24.8053	24.8226	-.1695E-01	.1422E-02	.1701E-01
52	-19.0000	.6650	23.6408	-.1750E-01	.6507E-03	.1751E-01
53	-19.0000	3.3317	23.6468	-.1749E-01	.6555E-03	.1751E-01
54	-19.0000	5.9983	23.6582	-.1750E-01	.7758E-03	.1751E-01
55	-19.0000	8.6650	23.6679	-.1749E-01	.7779E-03	.1750E-01
56	-19.0000	11.3317	23.6790	-.1747E-01	.9829E-03	.1750E-01
57	-19.0000	13.9983	23.6914	-.1746E-01	.8914E-03	.1748E-01
58	-19.0000	16.6650	23.7054	-.1742E-01	.1227E-02	.1746E-01
59	-19.0000	18.4366	23.7165	-.1741E-01	.1300E-02	.1746E-01
60	-19.0000	20.2081	23.7285	-.1740E-01	.1426E-02	.1745E-01
61	-19.0000	21.9797	23.7396	-.1729E-01	.1272E-02	.1734E-01
62	-19.0000	23.7513	23.7510	-.1715E-01	.1626E-02	.1723E-01
63	-9.5000	.3326	22.6146	-.1704E-01	.6616E-03	.1706E-01
64	-9.5000	5.6659	22.6276	-.1730E-01	.2515E-03	.1730E-01
65	-9.5000	10.9992	22.6382	-.1785E-01	.2181E-03	.1785E-01
66	-9.5000	16.3325	22.6554	-.1841E-01	.7230E-03	.1842E-01
67	-9.5000	19.5916	22.6720	-.1853E-01	.1072E-02	.1856E-01

68	-9.5000	22.8507	22.6999	-.1881E-01	.1523E-02	.1888E-01
69	0.0000	0.0000	22.0187	-.1625E-01	.5472E-03	.1626E-01
70	0.0000	2.6667	22.0198	-.1645E-01	-.1082E-03	.1645E-01
71	0.0000	5.3333	22.0138	-.1682E-01	-.7036E-03	.1683E-01
72	0.0000	8.0000	22.0005	-.1754E-01	-.1178E-02	.1758E-01
73	0.0000	10.6667	21.9824	-.1844E-01	-.1357E-02	.1849E-01
74	0.0000	13.3333	21.9630	-.1963E-01	-.1054E-02	.1966E-01
75	0.0000	16.0000	21.9543	-.2084E-01	.2746E-03	.2084E-01
76	0.0000	17.4875	21.9530	-.2085E-01	.6063E-03	.2086E-01
77	0.0000	18.9750	21.9619	-.2015E-01	.3198E-02	.2040E-01
78	0.0000	20.4625	21.9583	-.1723E-01	-.6053E-03	.1725E-01
79	0.0000	21.9500	21.9499	-.1303E-01	.4797E-02	.1388E-01
80	5.0000	-.1750	21.6386	-.1408E-01	.5103E-03	.1409E-01
81	5.0000	5.2167	21.6216	-.1463E-01	-.1716E-02	.1473E-01
82	5.0000	10.6083	21.5404	-.1645E-01	-.4333E-02	.1701E-01
83	5.0000	16.0000	21.3952	-.2228E-01	-.7387E-02	.2347E-01
84	5.0000	18.4875	21.3406	-.2877E-01	-.8311E-02	.2994E-01
85	5.0000	20.9750	21.4093	-.3876E-01	.1233E-02	.3878E-01
86	10.0000	-.3500	21.3117	-.1190E-01	.4069E-03	.1191E-01
87	10.0000	2.3750	21.3081	-.1205E-01	-.1002E-02	.1209E-01
88	10.0000	5.1000	21.2843	-.1222E-01	-.2450E-02	.1247E-01
89	10.0000	7.8250	21.2386	-.1282E-01	-.4467E-02	.1339E-01
90	10.0000	10.5500	21.1626	-.1316E-01	-.6606E-02	.1467E-01
91	10.0000	13.2750	21.0439	-.1477E-01	-.1182E-01	.1891E-01
92	10.0000	16.0000	20.8405	-.1834E-01	-.1846E-01	.2603E-01
93	10.0000	17.0000	20.7229	-.2195E-01	-.2765E-01	.3530E-01
94	10.0000	18.0000	20.5640	-.2712E-01	-.3361E-01	.4319E-01
95	10.0000	19.0000	20.3386	-.3816E-01	-.5540E-01	.6700E-01
96	10.0000	20.0000	20.0000	-.4059E-01	-.6203E-01	.7413E-01
97	10.7500	-.3763	21.2680	-.1145E-01	.4440E-03	.1146E-01
98	10.7500	5.0825	21.2400	-.1168E-01	-.2416E-02	.1191E-01
99	10.7500	10.5413	21.1166	-.1193E-01	-.6335E-02	.1351E-01
100	10.7500	16.0000	20.7902	-.1148E-01	-.1900E-01	.2219E-01
101	10.7500	18.0000	20.5162	-.8338E-02	-.3524E-01	.3621E-01
102	10.7500	20.0000	20.0000	-.1213E-12	-.6765E-01	.6765E-01
103	11.5000	-.4025	21.2256	-.1109E-01	.4093E-03	.1109E-01
104	11.5000	2.3313	21.2215	-.1115E-01	-.1037E-02	.1120E-01
105	11.5000	5.0650	21.1973	-.1123E-01	-.2466E-02	.1150E-01
106	11.5000	7.7988	21.1504	-.1118E-01	-.4523E-02	.1206E-01
107	11.5000	10.5325	21.0736	-.1120E-01	-.6516E-02	.1296E-01
108	11.5000	13.2663	20.9538	-.9976E-02	-.1166E-01	.1535E-01
109	11.5000	16.0000	20.7545	-.6984E-02	-.1635E-01	.1864E-01
110	11.5000	17.0000	20.6460	-.2641E-02	-.2630E-01	.2644E-01
111	11.5000	18.0000	20.5015	.3765E-02	-.3115E-01	.3137E-01
112	11.5000	19.0000	20.3048	.1725E-01	-.5015E-01	.5303E-01
113	11.5000	20.0000	20.0000	.3089E-01	-.5818E-01	.6585E-01
114	14.0000	-.4500	21.0948	-.9663E-02	.3604E-03	.9670E-02
115	14.0000	5.0087	21.0671	-.9792E-02	-.2363E-02	.1007E-01
116	14.0000	10.5033	20.9525	-.8722E-02	-.5998E-02	.1058E-01
117	14.0000	16.0000	20.7059	-.2502E-02	-.1228E-01	.1253E-01
118	14.0000	18.1475	20.5747	.6160E-02	-.1606E-01	.1627E-01
119	14.0000	20.2951	20.5297	.2394E-01	-.2834E-02	.2411E-01
120	16.5000	-.5775	20.9788	-.6692E-02	.3015E-03	.6697E-02
121	16.5000	2.1684	20.9748	-.6830E-02	-.9004E-03	.6877E-02
122	16.5000	4.9143	20.9539	-.6460E-02	-.2135E-02	.6725E-02
123	16.5000	7.7113	20.9151	-.7783E-02	-.3493E-02	.8540E-02
124	16.5000	10.4742	20.8574	-.6654E-02	-.4951E-02	.8455E-02
125	16.5000	13.2371	20.7799	-.4383E-02	-.5988E-02	.7420E-02
126	16.5000	16.0000	20.6919	-.1016E-02	-.6214E-02	.6297E-02
127	16.5000	17.1475	20.6575	.8224E-03	-.5112E-02	.5178E-02
128	16.5000	18.2951	20.6333	.2052E-02	-.2666E-02	.3360E-02
129	16.5000	19.4426	20.6097	.1332E-03	-.3761E-02	.3763E-02
130	16.5000	20.5902	20.5901	-.3381E-02	.2770E-02	.4371E-02
131	19.7500	-.6913	20.8477	-.7488E-02	.2803E-03	.7491E-02
132	19.7500	4.8725	20.8278	-.7240E-02	-.1708E-02	.7439E-02

139	23.0000	4.7967	20.7199	-.6227E-02	-.1316E-02	.6364E-02
140	23.0000	7.5976	20.6870	-.5808E-02	-.1890E-02	.6107E-02
141	23.0000	10.3883	20.6669	-.5311E-02	-.2398E-02	.5828E-02
142	23.0000	13.1992	20.6331	-.4581E-02	-.2292E-02	.5131E-02
143	23.0000	16.0000	20.6027	-.3886E-01	-.1848E-02	.4303E-02
144	23.0000	17.1446	20.5931	-.3686E-02	-.1476E-02	.3986E-02
145	23.0000	18.2892	20.5858	-.3513E-02	-.9316E-03	.3634E-02
146	23.0000	19.4337	20.5810	-.3500E-02	-.6592E-03	.3562E-02
147	23.0000	20.5783	20.5783	-.3500E-02	.1274E-03	.3502E-02
148	24.0000	-.6400	20.7036	-.6165E-02	.2071E-03	.6169E-02
149	24.0000	4.7733	20.6894	-.6002E-02	-.1240E-02	.6129E-02
150	24.0000	10.3867	20.6406	-.5270E-02	-.2246E-02	.5729E-02
151	24.0000	16.0000	20.5827	-.4150E-02	-.1738E-02	.4500E-02
152	24.0000	18.2804	20.5676	-.3798E-02	-.9325E-03	.3910E-02
153	24.0000	20.5608	20.5624	-.3514E-02	-.6080E-05	.3514E-02
154	25.0000	-.8750	20.6734	-.5910E-02	.1912E-03	.5913E-02
155	25.0000	1.9375	20.6715	-.5872E-02	-.4726E-03	.5891E-02
156	25.0000	4.7500	20.6601	-.5778E-02	-.1146E-02	.5890E-02
157	25.0000	7.5625	20.6403	-.5518E-02	-.1623E-02	.5752E-02
158	25.0000	10.3750	20.6146	-.5204E-02	-.2036E-02	.5588E-02
159	25.0000	13.1875	20.5861	-.4809E-02	-.1894E-02	.5169E-02
160	25.0000	16.0000	20.5612	-.4433E-02	-.1520E-02	.4686E-02
161	25.0000	17.1358	20.5536	-.4288E-02	-.1169E-02	.4454E-02
162	25.0000	18.2716	20.5478	-.4173E-02	-.7877E-03	.4243E-02
163	25.0000	19.4074	20.5444	-.4049E-02	-.4217E-03	.4071E-02
164	25.0000	20.5432	20.5431	-.3862E-02	.1279E-03	.3864E-02
165	28.2500	-.8888	20.5834	-.5187E-02	.1785E-03	.5190E-02
166	28.2500	4.6742	20.5720	-.5144E-02	-.1000E-02	.5241E-02
167	28.2500	10.3371	20.5319	-.4977E-02	-.1858E-02	.5312E-02
168	28.2500	16.0000	20.4832	-.5167E-02	-.1563E-02	.5398E-02
169	28.2500	18.2267	20.4708	-.5301E-02	-.6749E-03	.5372E-02
170	28.2500	20.4535	20.4677	-.5519E-02	.4883E-04	.5520E-02
171	31.5000	-1.1025	20.5046	-.4518E-02	.1607E-03	.4520E-02
172	31.5000	1.7479	20.5030	-.4534E-02	-.3837E-03	.4550E-02
173	31.5000	4.5863	20.4937	-.4540E-02	-.9196E-03	.4633E-02
174	31.5000	7.4488	20.4769	-.4583E-02	-.1413E-02	.4796E-02
175	31.5000	10.2992	20.4534	-.4677E-02	-.1882E-02	.5045E-02
176	31.5000	13.1496	20.4241	-.5205E-02	-.2111E-02	.5617E-02
177	31.5000	16.0000	20.3933	-.6047E-02	-.2018E-02	.6374E-02
178	31.5000	17.0909	20.3829	-.6546E-02	-.1577E-02	.6734E-02
179	31.5000	18.1819	20.3761	-.6846E-02	-.7230E-03	.6884E-02
180	31.5000	19.2728	20.3692	-.6064E-02	-.1131E-02	.6169E-02
181	31.5000	20.3637	20.3637	-.4789E-02	.1335E-02	.4971E-02
182	34.0000	-1.1900	20.4510	-.4062E-02	.1429E-03	.4064E-02
183	34.0000	4.5400	20.4400	-.4080E-02	-.9028E-03	.4179E-02
184	34.0000	10.2700	20.3980	-.4181E-02	-.2026E-02	.4646E-02
185	34.0000	16.0000	20.3173	-.5896E-02	-.3706E-02	.6796E-02
186	34.0000	18.0909	20.2785	-.8183E-02	-.4888E-02	.9431E-02
187	34.0000	20.1819	20.2573	-.1462E-01	-.9974E-03	.1466E-01
188	36.5000	-1.2776	20.4030	-.3617E-02	.1337E-03	.3619E-02
189	36.5000	1.6021	20.4012	-.3624E-02	-.3733E-03	.3643E-02
190	36.5000	4.4817	20.3922	-.3611E-02	-.8709E-03	.3714E-02
191	36.5000	7.3613	20.3755	-.3582E-02	-.1483E-02	.3877E-02
192	36.5000	10.2408	20.3495	-.3527E-02	-.2047E-02	.4077E-02
193	36.5000	13.1204	20.3115	-.3756E-02	-.3428E-02	.5083E-02
194	36.5000	16.0000	20.2509	-.4430E-02	-.5278E-02	.6891E-02
195	36.5000	17.0000	20.2190	-.5459E-02	-.7511E-02	.9286E-02
196	36.5000	18.0000	20.1757	-.7182E-02	-.9461E-02	.1188E-01
197	36.5000	19.0000	20.1121	-.1076E-01	-.1757E-01	.2060E-01
198	36.5000	20.0000	20.0000	-.1409E-01	-.2191E-01	.2605E-01
199	37.2500	-1.3038	20.3896	-.3489E-02	.1276E-03	.3492E-02
200	37.2500	4.4842	20.3790	-.3473E-02	-.8510E-03	.3578E-02
201	37.2500	10.2321	20.3386	-.3331E-02	-.1949E-02	.3860E-02
202	37.2500	16.0000	20.2371	-.3151E-02	-.5301E-02	.6167E-02
203	37.2500	18.0000	20.1595	-.2913E-02	-.1001E-01	.1042E-01
204	37.2500	20.0000	20.0000	-.1364E-12	-.2186E-01	.2186E-01
205	38.0000	-1.3300	20.3768	-.3368E-02	.1184E-03	.3370E-02
206	38.0000	1.5583	20.3751	-.3362E-02	-.3617E-03	.3381E-02
207	38.0000	4.4467	20.3663	-.3341E-02	-.8398E-03	.3445E-02
208	38.0000	7.3350	20.3500	-.3236E-02	-.1441E-02	.3542E-02
209	38.0000	.0.2233	20.3247	-.3140E-02	-.1998E-02	.3721E-02
210	38.0000	13.1117	20.2873	-.2741E-02	-.3375E-02	.4348E-02
211	38.0000	16.0000	20.2272	-.1902E-02	-.5223E-02	.5558E-02
212	38.0000	17.0000	20.1958	-.7801E-03	-.7333E-02	.7374E-02
213	38.0000	18.0000	20.1539	.9528E-03	-.9215E-02	.9264E-02
214	38.0000	19.0000	20.0843	.4960E-02	-.1539E-01	.1617E-01
215	38.0000	20.0000	20.0000	.9122E-02	-.1840E-01	.2054E-01
216	40.5000	-1.4175	20.3371	-.2984E-02	.1069E-03	.2986E-02
217	40.5000	4.3883	20.3276	-.2920E-02	-.7632E-03	.3018E-02
218	40.5000	10.1942	20.2904	-.2500E-02	-.1801E-02	.3081E-02
219	40.5000	16.0000	20.2144	-.6339E-03	-.3545E-02	.3601E-02
220	40.5000	18.0459	20.1781	.1784E-02	-.4438E-02	.4778E-02
221	40.5000	20.0917	20.1637	.7389E-02	-.1414E-02	.7523E-02
222	43.0000	-1.5056	20.3021	-.2829E-02	.9117E-04	.2830E-02
223	43.0000	1.4125	20.3007	-.2802E-02	-.2847E-03	.2818E-02
224	43.0000	4.3300	20.2938	-.2639E-02	-.6681E-03	.2625E-02
225	43.0000	7.2475	20.2812	-.2319E-02	-.1084E-02	.2551E-02
226	43.0000	10.1650	20.2627	-.2023E-02	-.1484E-02	.2509E-02
227	43.0000	13.0825	20.2385	-.1272E-02	-.1760E-02	.2171E-02
228	43.0000	16.0000	20.2114	-.2371E-03	-.1787E-02	.1803E-02
229	43.0000	17.0459	20.2024	.2610E-03	-.1474E-02	.1497E-02
230	43.0000	18.0917	20.1960	.5797E-03	-.7827E-03	.9621E-03
231	43.0000	19.1376	20.1892	.1603E-04	-.1199E-02	.1199E-02
232	43.0000	20.1834	20.1834	-.8982E-03	.8661E-03	.1248E-02
233	46.2500	-1.6188	20.2624	-.2271E-02	.7838E-04	.2273E-02
234	46.2500	4.2542	20.2566	-.2187E-02	-.5313E-03	.2251E-02
235	46.2500	10.1271	20.2328	-.1786E-02	-.1070E-02	.2083E-02
236	46.2500	16.0000	20.2017	-.7984E-03	-.1013E-02	.1291E-02
237	46.2500	18.0906	20.1938	-.4603E-03	-.6465E-03	.7938E-03
238	46.2500	20.1812	20.1812	-.1403E-03	-.9227E-04	.1679E-03
239	48.5000	-1.7325	20.2282	-.1958E-02	.7275E-04	.1960E-02
240	48.5000	1.2229	20.2274	-.1937E-02	-.1717E-03	.1945E-02
241	48.5000	4.1783	20.2231	-.1895E-02	-.4114E-03	.1939E-02
242	48.5000	7.1338	20.2166	-.1784E-02	-.5860E-03	.1869E-02
243	48.5000	10.0 92	20.2058	-.1610E-02	-.7408E-03	.1772E-02
244	48.5000	13.0446	20.1949	-.1390E-02	-.6897E-03	.1552E-02
245	48.5000	16.0000	20.1854	-.1179E-02	-.5323E-03	.1294E-02
246	48.5000	17.0447	20.1829	-.1135E-02	-.4200E-03	.1210E-02
247	48.5000	18.0894	20.1810	-.1100E-02	-.2817E-03	.1130E-02
248	48.5000	19.1342	20.1797	-.1109E-02	-.2049E-03	.1128E-02
249	48.5000	20.1789	20.1789	-.1118E-02	.3089E-04	.1118E-02
250	50.5000	-1.7676	20.2166	-.1881E-02	.6297E-04	.1882E-02
251	50.5000	4.1850	20.2138	-.1827E-02	-.3884E-03	.1868E-02
252	50.5000	10.0775	20.1976	-.1594E-02	-.6963E-03	.1743E-02
253	50.5000	16.0000	20.1793	-.1288E-02	-.5085E-03	.1383E-02
254	50.5000	18.0867	20.1753	-.1186E-02	-.2744E-03	.1217E-02
255	50.5000	20.1733	20.1738	-.1116E-02	-.1832E-04	.1116E-02
256	51.5000	-1.8025	20.2093	-.1806E-02	.5815E-04	.1807E-02
257	51.5000	1.1646	20.2087	-.1793E-02	-.1492E-03	.1799E-02
258	51.5000	4.1317	20.2046	-.1762E-02	-.3598E-03	.1798E-02
259	51.5000	7.0988	20.1984	-.1680E-02	-.5067E-03	.1755E-02
260	51.5000	10.0658	20.1899	-.1581E-02	-.6346E-03	.1704E-02
261	51.5000	13.0329	20.1807	-.1485E-02	-.5776E-03	.1575E-02
262	51.5000	16.0000	20.1727	-.1358E-02	-.4477E-03	.1430E-02
263	51.5000	17.0419	20.1707	-.1327E-02	-.3438E-03	.1371E-02
264	51.5000	18.0839	20.1692	-.1297E-02	-.2280E-03	.1317E-02
265	51.5000	19.1258	20.1681	-.1288E-02	-.1395E-03	.1275E-02

[illegible]	[illegible]	16.0000	20.1488	-.1592E-02	-.4759E-03	.1661E-02
271	54.7500	18.0698	20.1452	-.1644E-02	-.2824E-03	.1668E-02
272	54.7500	20.1388	20.1441	-.1728E-02	-.1927E-04	.1728E-02
273	58.0000	-2.0300	20.1578	-.1393E-02	.4966E-04	.1394E-02
274	58.0000	.9750	20.1570	-.1397E-02	-.1193E-03	.1402E-02
275	58.0000	3.9800	20.1540	-.1398E-02	-.2887E-03	.1428E-02
276	58.0000	6.9850	20.1488	-.1404E-02	-.4383E-03	.1471E-02
277	58.0000	9.9900	20.1408	-.1426E-02	-.5884E-03	.1543E-02
278	58.0000	12.9950	20.1312	-.1592E-02	-.6590E-03	.1723E-02
279	58.0000	16.0000	20.1210	-.1864E-02	-.6324E-03	.1969E-02
280	58.0000	17.0279	20.1179	-.2014E-02	-.5098E-03	.2078E-02
281	58.0000	18.0558	20.1158	-.2103E-02	-.2663E-03	.2120E-02
282	58.0000	19.0837	20.1135	-.1886E-02	-.4099E-03	.1930E-02
283	58.0000	20.1116	20.1116	-.1554E-02	.3436E-03	.1591E-02
284	60.5000	-2.1176	20.1410	-.1280E-02	.4426E-04	.1281E-02
285	60.5000	3.9217	20.1374	-.1262E-02	-.2772E-03	.1292E-02
286	60.5000	9.9608	20.1239	-.1283E-02	-.6202E-03	.1425E-02
287	60.5000	16.0000	20.0976	-.1753E-02	-.1153E-02	.2098E-02
288	60.5000	18.0279	20.0858	-.2489E-02	-.1483E-02	.2897E-02
289	60.5000	20.0558	20.0814	-.4474E-02	-.6062E-03	.4503E-02
290	63.0000	-2.2050	20.1290	-.1130E-02	.4178E-04	.1131E-02
291	63.0000	.8292	20.1255	-.1131E-02	-.1132E-03	.1137E-02
292	63.0000	3.8633	20.1226	-.1128E-02	-.2649E-03	.1158E-02
293	63.0000	6.8975	20.1172	-.1113E-02	-.4507E-03	.1201E-02
294	63.0000	9.9317	20.1089	-.1091E-02	-.6186E-03	.1254E-02
295	63.0000	12.9658	20.0968	-.1160E-02	-.1048E-02	.1569E-02
296	63.0000	16.0000	20.0772	-.1391E-02	-.1630E-02	.2123E-02
297	63.0000	17.0000	20.0673	-.1671E-02	-.2322E-02	.2861E-02
298	63.0000	18.0000	20.0540	-.2191E-02	-.2923E-02	.3653E-02
299	63.0000	19.0000	20.0343	-.3224E-02	-.5396E-02	.6286E-02
300	63.0000	20.0000	20.0000	-.4189E-02	-.6793E-02	.7981E-02
301	63.7500	-2.2313	20.1219	-.1093E-02	.3989E-04	.1094E-02
302	63.7500	3.8458	20.1185	-.1086E-02	-.2585E-03	.1116E-02
303	63.7500	9.9229	20.1050	-.1036E-02	-.6004E-03	.1197E-02
304	63.7500	16.0000	20.0730	-.9669E-03	-.1633E-02	.1898E-02
305	63.7500	18.0000	20.0490	-.6877E-03	-.3088E-02	.3211E-02
306	63.7500	20.0000	20.0000	-.1364E-12	-.6702E-02	.6702E-02
307	64.5000	-2.2575	20.1178	-.1058E-02	.3720E-04	.1059E-02
308	64.5000	.7854	20.1173	-.1056E-02	-.1092E-03	.1061E-02
309	64.5000	3.8283	20.1145	-.1048E-02	-.2548E-03	.1078E-02
310	64.5000	6.8713	20.1093	-.1013E-02	-.4368E-03	.1103E-02
311	64.5000	9.9142	20.1012	-.9825E-03	-.5023E-03	.1152E-02
312	64.5000	12.9571	20.0893	-.8554E-03	-.1029E-02	.1338E-02
313	64.5000	16.0000	20.0689	-.5870E-03	-.1608E-02	.1712E-02
314	64.5000	17.0000	20.0602	-.2384E-03	-.2261E-02	.2274E-02
315	64.5000	18.0000	20.0473	.2970E-03	-.2836E-02	.2852E-02
316	64.5000	19.0000	20.0290	.1508E-02	-.4731E-02	.4965E-02
317	64.5000	20.0000	20.0000	.2769E-02	-.5880E-02	.6319E-02
318	67.0000	-2.3450	20.1053	-.8467E-03	.3387E-04	.8473E-03
319	67.0000	3.7700	20.1023	-.9260E-03	-.2316E-03	.9545E-03
320	67.0000	9.8850	20.0904	-.7860E-03	-.5468E-03	.9649E-03
321	67.0000	16.0000	20.0659	-.2028E-03	-.1091E-02	.1110E-02
322	67.0000	18.0141	20.0549	.5256E-03	-.1361E-02	.1459E-02
323	67.0000	20.0282	20.0504	.2283E-02	-.4854E-03	.2315E-02
324	69.5000	-2.4325	20.0841	-.8440E-03	.2932E-04	.8446E-03
325	69.5000	.6396	20.0837	-.8356E-03	-.8598E-04	.8400E-03
326	69.5000	3.7117	20.0815	-.8163E-03	-.2029E-03	.8411E-03
327	69.5000	6.7838	20.0874	-.7483E-03	-.3253E-03	.8160E-03
328	69.5000	9.8558	20.0815	-.5580E-03	-.4556E-03	.7203E-03
329	69.5000	12.9279	20.0736	-.4202E-03	-.5421E-03	.6859E-03
330	69.5000	16.0000	20.0648	-.8813E-04	-.5488E-03	.5558E-03
331	69.5000	17.0141	20.0622	.5016E-04	-.4528E-03	.4556E-03
332	69.5000	18.0282	20.0603	.1533E-03	-.2454E-03	.2894E-03
333	69.5000	19.0423	20.0582	-.1714E-04	-.3751E-03	.3755E-03
334	69.5000	20.0565	20.0564	-.2798E-03	.2684E-03	.3863E-03
335	72.7500	-2.5463	20.0813	-.7390E-03	.2559E-04	.7394E-03
336	72.7500	3.6358	20.0792	-.7123E-03	-.1630E-03	.7307E-03
337	72.7500	9.8179	20.0717	-.5791E-03	-.3317E-03	.6673E-03
338	72.7500	16.0000	20.0618	-.2675E-03	-.3104E-03	.4098E-03
339	72.7500	18.0277	20.0592	-.1659E-03	-.1978E-03	.2580E-03
340	72.7500	20.0553	20.0585	-.6880E-04	-.2915E-04	.7484E-04
341	76.0000	-2.6600	20.0701	-.6474E-03	.2392E-04	.6479E-03
342	76.0000	.4600	20.0699	-.6401E-03	-.5213E-04	.6422E-03
343	76.0000	3.5800	20.0685	-.6263E-03	-.1270E-03	.6391E-03
344	76.0000	6.6700	20.0660	-.5832E-03	-.1820E-03	.6110E-03
345	76.0000	9.7600	20.0628	-.5327E-03	-.2318E-03	.5809E-03
346	76.0000	12.8500	20.0592	-.4593E-03	-.2139E-03	.5067E-03
347	76.0000	16.0000	20.0562	-.3895E-03	-.1821E-03	.4219E-03
348	76.0000	17.0136	20.0554	-.3768E-03	-.1271E-03	.3978E-03
349	76.0000	18.0271	20.0549	-.3671E-03	-.7872E-04	.3755E-03
350	76.0000	19.0407	20.0545	-.3709E-03	-.6358E-04	.3763E-03
351	76.0000	20.0542	20.0542	-.3740E-03	.8588E-05	.3741E-03
352	77.0000	-2.6950	20.0659	-.6240E-03	.2103E-04	.6244E-03
353	77.0000	3.5387	20.0654	-.6068E-03	-.1197E-03	.6175E-03
354	77.0000	9.7663	20.0602	-.5268E-03	-.2173E-03	.5717E-03
355	77.0000	16.0000	20.0541	-.4188E-03	-.1540E-03	.4444E-03
356	77.0000	18.0282	20.0530	-.3932E-03	-.8332E-04	.4019E-03
357	77.0000	20.0524	20.0525	-.3720E-03	-.5811E-05	.3721E-03
358	78.0000	-2.7300	20.0638	-.6021E-03	.1948E-04	.6024E-03
359	78.0000	.3817	20.0636	-.5972E-03	-.4495E-04	.5989E-03
360	78.0000	3.5133	20.0624	-.5884E-03	-.1107E-03	.5988E-03
361	78.0000	6.6350	20.0603	-.5578E-03	-.1568E-03	.5794E-03
362	78.0000	9.7567	20.0575	-.5236E-03	-.1975E-03	.5595E-03
363	78.0000	12.8783	20.0546	-.4830E-03	-.1781E-03	.5148E-03
364	78.0000	16.0000	20.0520	-.4463E-03	-.1358E-03	.4665E-03
365	78.0000	17.0126	20.0514	-.4367E-03	-.1037E-03	.4489E-03
366	78.0000	18.0253	20.0509	-.4276E-03	-.6839E-04	.4332E-03
367	78.0000	19.0379	20.0508	-.4194E-03	-.4280E-04	.4216E-03
368	78.0000	20.0505	20.0505	-.4154E-03	.4064E-05	.4154E-03
369	81.2500	-2.8438	20.0548	-.5391E-03	.1835E-04	.5394E-03
370	81.2500	3.4375	20.0534	-.5312E-03	-.6423E-04	.5395E-03
371	81.2500	9.7187	20.0492	-.5050E-03	-.1798E-03	.5348E-03
372	81.2500	16.0000	20.0441	-.5178E-03	-.1403E-03	.5365E-03
373	81.2500	18.0208	20.0431	-.5312E-03	-.6324E-04	.5378E-03
374	81.2500	20.0416	20.0428	-.5640E-03	-.7600E-05	.5541E-03
375	84.5000	-2.9575	20.0463	-.4820E-03	.1714E-04	.4823E-03
376	84.5000	.2021	20.0462	-.4818E-03	-.3337E-04	.4830E-03
377	84.5000	3.3617	20.0452	-.4799E-03	-.6317E-04	.4868E-03
378	84.5000	6.5213	20.0436	-.4778E-03	-.1281E-03	.4947E-03
379	84.5000	9.6808	20.0412	-.4788E-03	-.1722E-03	.5098E-03
380	84.5000	12.8404	20.0382	-.5233E-03	-.1912E-03	.5572E-03
381	84.5000	16.0000	20.0352	-.5883E-03	-.1811E-03	.6251E-03
382	84.5000	17.0081	20.0343	-.6383E-03	-.1468E-03	.6550E-03
383	84.5000	18.0162	20.0337	-.6818E-03	-.6023E-04	.6865E-03
384	84.5000	19.0244	20.0330	-.6087E-03	-.1170E-03	.6199E-03
385	84.5000	20.0325	20.0325	-.5222E-03	.6843E-04	.5293E-03
386	87.0000	-3.0450	20.0405	-.4448E-03	.1559E-04	.4448E-03
387	87.0000	3.3033	20.0385	-.4425E-03	-.7851E-04	.4494E-03
388	87.0000	9.6517	20.0354	-.4413E-03	-.1773E-03	.4756E-03
389	87.0000	16.0000	20.0276	-.5747E-03	-.3243E-03	.6599E-03
390	87.0000	18.0081	20.0244	-.7728E-03	-.3987E-03	.8696E-03
391	87.0000	20.0162	20.0231	-.1301E-02	-.1514E-03	.1310E-02
392	89.5000	-3.1325	20.0352	-.4089E-03	.1507E-04	.4092E-03
393	89.5000	.0562	20.0351	-.4082E-03	-.2854E-04	.4093E-03
394	89.5000	3.2450	20.0342	-.4052E-03	-.7302E-04	.4117E-03
395	89.5000	6.4338	20.0327	-.3986E-03	-.1258E-03	.4180E-03
396	89.5000	9.6225	20.0302	-.3886E-03	-.1735E-03	.4255E-03
397	89.5000	12.8113	20.0266	-.4086E-03	-.2958E-03	.5043E-03

402	89.5000	20.0000	20.0000	-.1168E-02	-.1818E-02	.2161E-02
403	90.2500	-3.1588	20.0337	-.3888E-03	.1463E-04	.3891E-03
404	90.2500	3.2275	20.0327	-.3946E-03	-.7073E-04	.4008E-03
405	90.2500	8.6138	20.0288	-.3749E-03	-.1872E-03	.4108E-03
406	90.2500	16.0000	20.0182	-.3899E-03	-.4708E-03	.6983E-03
407	90.2500	18.0000	20.0125	-.3881E-03	-.8468E-03	.9333E-03
408	90.2500	20.0000	20.0000	-.2274E-12	-.1652E-02	.1652E-02
409	91.0000	-3.1850	20.0322	-.3878E-03	.1287E-04	.3880E-03
410	91.0000	.0125	20.0321	-.3863E-03	-.2788E-04	.3873E-03
411	91.0000	3.2100	20.0313	-.3823E-03	-.8854E-04	.3888E-03
412	91.0000	8.4075	20.0288	-.3692E-03	-.1208E-03	.3888E-03
413	91.0000	9.6050	20.0274	-.3537E-03	-.1688E-03	.3919E-03
414	91.0000	12.8025	20.0239	-.3119E-03	-.2841E-03	.4267E-03
415	91.0000	16.0000	20.0180	-.2218E-03	-.4663E-03	.5073E-03
416	91.0000	17.0000	20.0152	-.1383E-03	-.6538E-03	.6683E-03
417	91.0000	18.0000	20.0116	-.2758E-04	-.7818E-03	.7821E-03
418	91.0000	19.0000	20.0085	.2019E-03	-.1148E-02	.1165E-02
419	91.0000	20.0000	20.0000	.4239E-03	-.1241E-02	.1311E-02
420	96.0000	-3.3600	20.0232	-.3349E-03	.1188E-04	.3351E-03
421	96.0000	3.0350	20.0225	-.3263E-03	-.5188E-04	.3304E-03
422	96.0000	9.4300	20.0198	-.2832E-03	-.1235E-03	.3090E-03
423	96.0000	15.8250	20.0148	-.1377E-03	-.2061E-03	.2479E-03
424	96.0000	17.9150	20.0134	-.1393E-04	-.2298E-03	.2303E-03
425	96.0000	20.0081	20.0134	.2034E-03	-.1128E-03	.2324E-03
426	101.0000	-3.5350	20.0184	-.2852E-03	.9764E-05	.2854E-03
427	101.0000	-.3375	20.0164	-.2825E-03	-.1102E-04	.2828E-03
428	101.0000	2.8600	20.0151	-.2758E-03	-.3067E-04	.2773E-03
429	101.0000	6.0575	20.0144	-.2588E-03	-.4949E-04	.2634E-03
430	101.0000	9.2550	20.0135	-.2387E-03	-.6179E-04	.2447E-03
431	101.0000	12.4525	20.0124	-.2037E-03	-.6187E-04	.2129E-03
432	101.0000	15.6500	20.0115	-.1688E-03	-.3868E-04	.1736E-03
433	101.0000	16.7400	20.0112	-.1731E-03	-.4748E-04	.1795E-03
434	101.0000	17.8301	20.0110	-.1849E-03	.9098E-05	.1851E-03
435	101.0000	18.9201	20.0106	-.2358E-03	-.7438E-04	.2471E-03
436	101.0000	20.0102	20.0102	-.2838E-03	.5500E-04	.2888E-03
437	110.5000	-3.8875	20.0027	-.2544E-03	.8217E-05	.2545E-03
438	110.5000	2.5275	20.0027	-.2498E-03	-.9882E-05	.2498E-03
439	110.5000	8.9225	20.0023	-.2334E-03	-.2138E-04	.2344E-03
440	110.5000	15.3175	20.0019	-.2131E-03	-.1693E-04	.2138E-03
441	110.5000	17.6591	20.0018	-.2075E-03	-.1336E-04	.2079E-03
442	110.5000	20.0007	20.0018	-.1995E-03	-.7071E-05	.1996E-03
443	120.0000	-4.2000	19.9912	-.2315E-03	.9005E-05	.2316E-03
444	120.0000	-1.0025	19.9913	-.2315E-03	.5104E-05	.2315E-03
445	120.0000	2.1950	19.9914	-.2309E-03	.3535E-05	.2309E-03
446	120.0000	5.3925	19.9914	-.2302E-03	-.1016E-06	.2302E-03
447	120.0000	8.5900	19.9914	-.2294E-03	.8551E-06	.2294E-03
448	120.0000	11.7875	19.9913	-.2290E-03	-.2168E-05	.2290E-03
449	120.0000	14.9850	19.9913	-.2290E-03	.9703E-06	.2290E-03
450	120.0000	16.2366	19.9913	-.2298E-03	-.1505E-05	.2298E-03
451	120.0000	17.4881	19.9913	-.2301E-03	.1400E-05	.2301E-03
452	120.0000	18.7397	19.9913	-.2323E-03	-.6632E-05	.2323E-03
453	120.0000	19.9912	19.9912	-.2341E-03	.2293E-05	.2341E-03
454	132.3500	-4.6323	19.9770	-.2278E-03	.7638E-05	.2277E-03
455	132.3500	1.7628	19.9772	-.2273E-03	.4727E-05	.2273E-03
456	132.3500	8.1578	19.9773	-.2261E-03	.2192E-06	.2261E-03
457	132.3500	14.5528	19.9774	-.2249E-03	.7032E-06	.2249E-03
458	132.3500	17.2651	19.9774	-.2248E-03	.1137E-06	.2248E-03
459	132.3500	19.9774	19.9774	-.2240E-03	-.3590E-06	.2240E-03
460	144.7000	-5.0848	19.9631	-.2218E-03	.7663E-05	.2218E-03
461	144.7000	-1.8670	19.9632	-.2219E-03	.6631E-05	.2220E-03
462	144.7000	1.3305	19.9633	-.2219E-03	.5870E-05	.2220E-03
463	144.7000	4.5280	19.9634	-.2221E-03	.4638E-05	.2221E-03
464	144.7000	7.7255	19.9634	-.2222E-03	.3970E-05	.2222E-03
465	144.7000	10.9230	19.9635	-.2223E-03	.2739E-05	.2223E-03
466	144.7000	14.1205	19.9635	-.2223E-03	.2074E-05	.2224E-03
467	144.7000	15.5813	19.9635	-.2224E-03	.1443E-05	.2224E-03
468	144.7000	17.0420	19.9635	-.2224E-03	.1288E-05	.2224E-03
469	144.7000	18.5028	19.9636	-.2228E-03	.3288E-06	.2228E-03
470	144.7000	19.9636	19.9636	-.2228E-03	.5674E-06	.2228E-03
471	179.8500	-6.2948	19.9249	-.2121E-03	.7347E-05	.2123E-03
472	179.8500	.1002	19.9251	-.2123E-03	.5576E-05	.2123E-03
473	179.8500	6.4953	19.9252	-.2124E-03	.3832E-05	.2124E-03
474	179.8500	12.8903	19.9253	-.2124E-03	.2101E-05	.2124E-03
475	179.8500	16.4082	19.9254	-.2124E-03	.1146E-05	.2124E-03
476	179.8500	19.9262	19.9254	-.2124E-03	.1820E-06	.2124E-03
477	215.0000	-7.5250	19.8884	-.2030E-03	.7147E-05	.2031E-03
478	215.0000	-4.3275	19.8885	-.2028E-03	.5887E-05	.2030E-03
479	215.0000	-1.1300	19.8886	-.2028E-03	.5800E-05	.2029E-03
480	215.0000	2.0675	19.8887	-.2028E-03	.4337E-05	.2028E-03
481	215.0000	5.2650	19.8887	-.2027E-03	.4016E-05	.2027E-03
482	215.0000	8.4625	19.8888	-.2027E-03	.2878E-05	.2027E-03
483	215.0000	11.6600	19.8886	-.2028E-03	.2374E-05	.2028E-03
484	215.0000	13.7172	19.8889	-.2028E-03	.1818E-05	.2028E-03
485	215.0000	15.7744	19.8888	-.2026E-03	.1283E-05	.2028E-03
486	215.0000	17.8317	19.8889	-.2028E-03	.6311E-06	.2028E-03
487	215.0000	19.8889	19.8889	-.2026E-03	.2231E-06	.2026E-03
488	253.0000	-8.8550	19.8507	-.1930E-03	.6134E-05	.1931E-03
489	253.0000	-2.4600	19.8509	-.1935E-03	.4549E-05	.1936E-03
490	253.0000	3.9350	19.8510	-.1940E-03	.3204E-05	.1940E-03
491	253.0000	10.3300	19.8511	-.1942E-03	.1938E-05	.1943E-03
492	253.0000	15.0910	19.8512	-.1944E-03	.1048E-05	.1944E-03
493	253.0000	19.8519	19.8512	-.1944E-03	.1176E-06	.1944E-03
494	291.0000	-10.1850	19.8150	-.1825E-03	.1828E-05	.1825E-03
495	291.0000	-6.9875	19.8150	-.1833E-03	.8882E-14	.1833E-03
496	291.0000	-3.7900	19.8150	-.1841E-03	.1026E-05	.1841E-03
497	291.0000	-.5925	19.8150	-.1848E-03	-.5968E-14	.1848E-03
498	291.0000	2.6050	19.8150	-.1853E-03	.7019E-06	.1853E-03
499	291.0000	5.8025	19.8150	-.1858E-03	-.8942E-14	.1858E-03
500	291.0000	9.0000	19.8150	-.1861E-03	.4027E-06	.1861E-03
501	291.0000	11.7038	19.8150	-.1864E-03	0.	.1864E-03
502	291.0000	14.4075	19.8150	-.1865E-03	.2088E-06	.1865E-03
503	291.0000	17.1113	19.8150	-.1866E-03	0.	.1866E-03
504	291.0000	19.8150	19.8150	-.1867E-03	-.1499E-06	.1867E-03

SEEPAGE FACE COMPUTATION RESULTS

NB = 96 NE = 113 AVE. VEL = .89950E-01 DS = .15000E+01 DQ = .10499E+00 ← #1 Trench q_1

TOTAL DISCHARGE = .10499E+00

NB = 113 NE = 198 AVE. VEL = .45950E-01 DS = 25000E+02 DQ = .11488E+01

TOTAL DISCHARGE = .12537E+01

NB = 198 NE = 215 AVE. VEL = .23295E-01 DS = 15000E+01 DQ = .34942E-01 ← #2 Trench q_2

TOTAL DISCHARGE = .12887E+01

NB = 215 NE = 300 AVE VEL = .14260E-01 DS = .25000E+02 DQ = .35650E+00

TOTAL DISCHARGE = .16452E+01

NB = 300 NE = 317 AVE VEL = .71501E-02 DS = .15000E+01 DQ = .10725E-01 ← #3 Trench q_3

TOTAL DISCHARGE = .16559E+01

NB = 317 NE = 402 AVE VEL = .42404E-02 DS = 25000E+02 DQ = 10601E+00

TOTAL DISCHARGE = 17619E+01

NB = 402 NE = 418 AVE VEL = .17352E-02 DS = 15000E+01 DQ = 26043E-02 ← #4 Trench q_4

TOTAL DISCHARGE = 17645E+01

1 "End of Problem"

APPENDIX C

DISCRIPTION OF COMPUTER PROCEDURES

APPENDIX C

Using a Personal Computer in Running
the Aral Seepage Program

I. Introduction:

The Aral Seepage Program is located on the Georgia Institute of Technology main frame computer in the Cyber B area. To run many runs of the program it is very convenient to prepare and edit the data files on a personal computer, using an editor or word processor. A brief description of the method for this particular program follows. A user should get instruction and information for use of the Cyber B from the Office of Computer Services, Rich Building, Georgia Institute of Technology.

II. Preparing the Data Files:

Using the Aral Seepage Program User's Manual (Pirtle, Appendix A) draw and label the mesh for the problem to be run. An example is Figure 3-5 of this study, but a working copy of the mesh should be large enough for easy referral and use. With the mesh and a complete list of problem characteristics a data file can be prepared, from the user's manual instructions.

In this study the number of nodes and basic shape of the mesh was to be unchanged for all of the runs. To

simplify preparing the data files a spreadsheet was prepared. Changing the dimensions or hydraulic conductivities (vertical or horizontal) required one entry and the spreadsheet adjusted the node positions from simple formulas. The complexity of the spreadsheet is entirely dependent on the problem considered and the skill of the user with a spreadsheet program. Any of the commercially available programs will work satisfactorily. If the study will involve several different mesh arrangements and/or only a few runs the data file can more easily be prepared on an editor by typing it in, if the editor is set to create an ASCII file.

An ASCII file is a file of the characters as entered. Word processing programs and spreadsheet programs have hidden command codes which control the programs so that the features are executed. Features are the calculation of values in a spreadsheet or the margins, justification and format of a word processor.

Most spreadsheet programs have a function or ancillary utility program for conversion of the spreadsheet to a values separated by commas ASCII format. With that utility the spreadsheet no longer will do calculations or have the simple column alignment.

In this study the programs available provided an ASCII file with all values separated by commas. The file did have commas to separate what had been empty cells

within the spreadsheet. Other programs may not have that result. To delete the commas a word processor was used. A program which allows editing an ASCII file is necessary for this operation. If a word processor is used in the normal mode of edit command codes will be imbedded to set margins and the file will not run properly on the Aral Seepage Program.

III. Sending the Data File:

With a proper data file prepared running the Aral Seepage Program from a personal computer requires one device and several clearances. An authorization to use the Cyber B must be obtained, with a file storage area, a password and an identification code. This is explained by manuals available at the Office of Computer Services. Access to the Aral Seepage Program, named OWRCC must now be obtained from the School of Civil Engineering at the Mason Building. The device needed is a MODEM for transfer of data and commands to the Cyber B. The speed and manufacture of the MODEM is subject to the needs of the user.

A communications program is necessary to use the MODEM and many such programs are available. Georgia Tech offers students and faculty a program named COGITATE for use in communicating. In this study a different program was used but, it had the KERMIT file transfer program and

this is necessary.

With the communications program call the GTNET system and when a connection is made enter the GTNET command:

>> **Connect *OCS CYBER B**

A connection to this directory will be made and right to access will be challenged:

Family **CYBERB**

Userid **(input the assigned ID)**

Password **(input the selected password)**

Access will be granted to the Cyber B area. To copy the data file to your file for execution of the Aral Seepage Program the program COGITATE has menu entries to execute. If another communication program is used the KERMIT protocol is necessary. The details of this description are better left to someone else. In this study the following procedure worked.

\ **KERMIT2**

Control was now with the user's computer by use of KERMIT commands. Executing the "Send" command of KERMIT and naming the data file to be downloaded successfully transferred the file. The file name was changed as the cyber will use the first eight alpha-numeric characters of the name and ignore any periods normally used to separate suffixes in the MS-DOS environment. At the completion of sending data files execute the KERMIT command to "Finish" and control will be re-established

with the Cyber.

IV. Running the Program:

To run the program and receive a printed output from the laser printers in the Rich Building do the following:

\ **OLD,OWRCC**

\ **GET,DATA** (note:DATA is data file as named upon receipt by Cyber. To see names answer \ with **LF**)

\ **OWRCC,DATA,PRINT** (note:PRINT is name selected for the output by user. If no print is specified the output of the run will go to the screen. With a MODEM this is a very long process and is not recommended.)

A short wait of less then a minute can normally be expected here. If an error message is received the data file should be checked for errors in concept and tried again. If a transfer error is suspected send the file a second time.

\ **SAVE,PRINT** (note:SAVE only if a copy of the output is desired for the holding on Cyber)

\ **PRINT?** (note:A hard copy of the program output will be received in the Rich Building if the output file name **PRINT** is input at the first query and all other entries are allowed to default by responding with the "ENTER" or "RETURN" key. The last query asks for the USERID and responding with the ID has it printed on the cover of the hard copy for easier identification.

There are several other printer locations and many options one can exercise in printing the results. For more information consult the advisors in the Rich Building.

To exit from the Cyber:

\ **LOGOUT**

>> **LOGOUT**

V. <u>Caution:</u>

This appendix **is not** a replacement for the user's manuals of the programs used, nor for the instructions and guidance of the Office of Computer Services. It **is** a quick and easy guide of a procedure that has been successful in running programs on the Aral Seepage Program.

As stressed above many different programs will do the functions of the above procedure. For information the following were used:

Spreadsheet: SuperCalc 3

Editor: WordStar 4.0

Communications: ProComm 2.1

It would be an advantage if the output file from the Aral Seepage Program could be captured and downloaded from the Cyber. This was attempted with KERMIT once but, was discontinued after twenty minutes of transfer with a 1200 Baud MODEM.

APPENDIX D

SPREADSHEET AND DATA FILE DISKS

APPENDIX E

ARBITRARY SELECTION OF RADIUS

APPENDIX E

Arbitrary Selection of Radius

In this study the radius of influence was determined as the distance at which no more then a 10% decrease in total flow over a 100 foot change in trial radii occurs. This arbitrary selection is certainly open to discussion. It is very common for less restrictive criteria to be used in the definition of radius of influence of drawdown.

Figures E-1 and E-2 are cross section drawings of the free water surface in the trench area if the radius of influence had been selected at lower values based on some different arbitrary standard. Obviously the free surface reaches the upper blanket and possibly the foundation. The formulas used in Chapter 4 were based on field data of seepage and the field interpretation of the radius of influence, under some standard determination.

If the selection of radius of influence for this study had been based on a different criteria the predictive forms and dimensionless products would have been changed. Using a standard of 0.1 ft^3/day/ft, maximum change in trial radii of influence, Criteria A, results in Figures E-3 and E-4. These figures are the dimensionless product for a different standard of radius of influence. The new standard is on average 0.07 ft^3/day/ft less restrictive and predict the radii of

TABLE E-1

SUMMARY OF DATA, CRITERIA A RADIUS DETERMINATION

Slope	Sp	Hr	h	Li´ (ft)	q´ ft^2/day	F´ (ft)
0	15	20	10	250	0.18	0.28
0	25	20	10	250	0.15	0.31
0	35	20	10	250	0.15	0.36
0	15	20	20	400	0.25	0.4
0	25	20	20	400	0.22	0.45
0	35	20	20	350	0.22	0.58
0	15	60	10	350	0.22	0.45
0	25	60	10	300	0.21	0.65
0	35	60	10	300	0.2	0.75
0	15	60	20	450	0.35	0.76
0	25	60	20	450	0.32	0.93
0	35	60	20	450	0.3	1.05
3.5	15	20	10	200	0.2	0.48
3.5	25	20	10	100	0.21	0.73
3.5	35	20	10			
3.5	15	20	20	400	0.25	0.6
3.5	25	20	20	250	0.25	0.95
3.5	35	20	20	300	0.25	0.98
3.5	15	60	10	300	0.21	0.65
3.5	25	60	10	200	0.24	1.1
3.5	35	60	10	150	0.25	1.4
3.5	15	60	20	450	0.32	0.92
3.5	25	60	20	425	0.3	1.27
3.5	35	60	20	400	0.3	1.55
7	15	20	10	100	0.3	0.81
7	25	20	10			
7	35	20	10			
7	15	20	20	225	0.38	0.98
7	25	20	20	175	0.39	1.25
7	35	20	20	125	0.39	1.85
7	15	60	10	150	0.3	1.05
7	25	60	10	75	0.38	1.8
7	35	60	10	50	0.4	2.1
7	15	60	20	350	0.38	1.21
7	25	60	20	300	0.39	1.8
7	35	60	20	225	0.41	2.42

Table E-1. The new curves of dimensionless products in Figures E-3 and E-4 show the less restrictive curves to be nearly unchanged.

As a further check a second standard, Criteria B was developed. This standard is defined as a total flow increase of 75% from the total flow at a trial radius of 700 feet. The scatter plot of the dimensionless product versus total flow and maximum free surface is shown by Figures E-5 and E-6 for Criteria A and Criteria B. Table E-7 summarizes the results of Criteria B.

Figures E-7 and E-8 show the final curves for total flow and the maximum free surface against the dimensionless product for all considered standards. The curves are little changed. The use of one composit curve would suffice in predicting total flow and maximum free surface for any standard of radii determination.

An incorrect radius of influence will under predict the flow and maximum free surface if too high. A conservative approach would be to reduce the radius of influence as predicted from Figures 4-1,2 and 3. The amount of adjustment would require additional field data from a trench drain system.

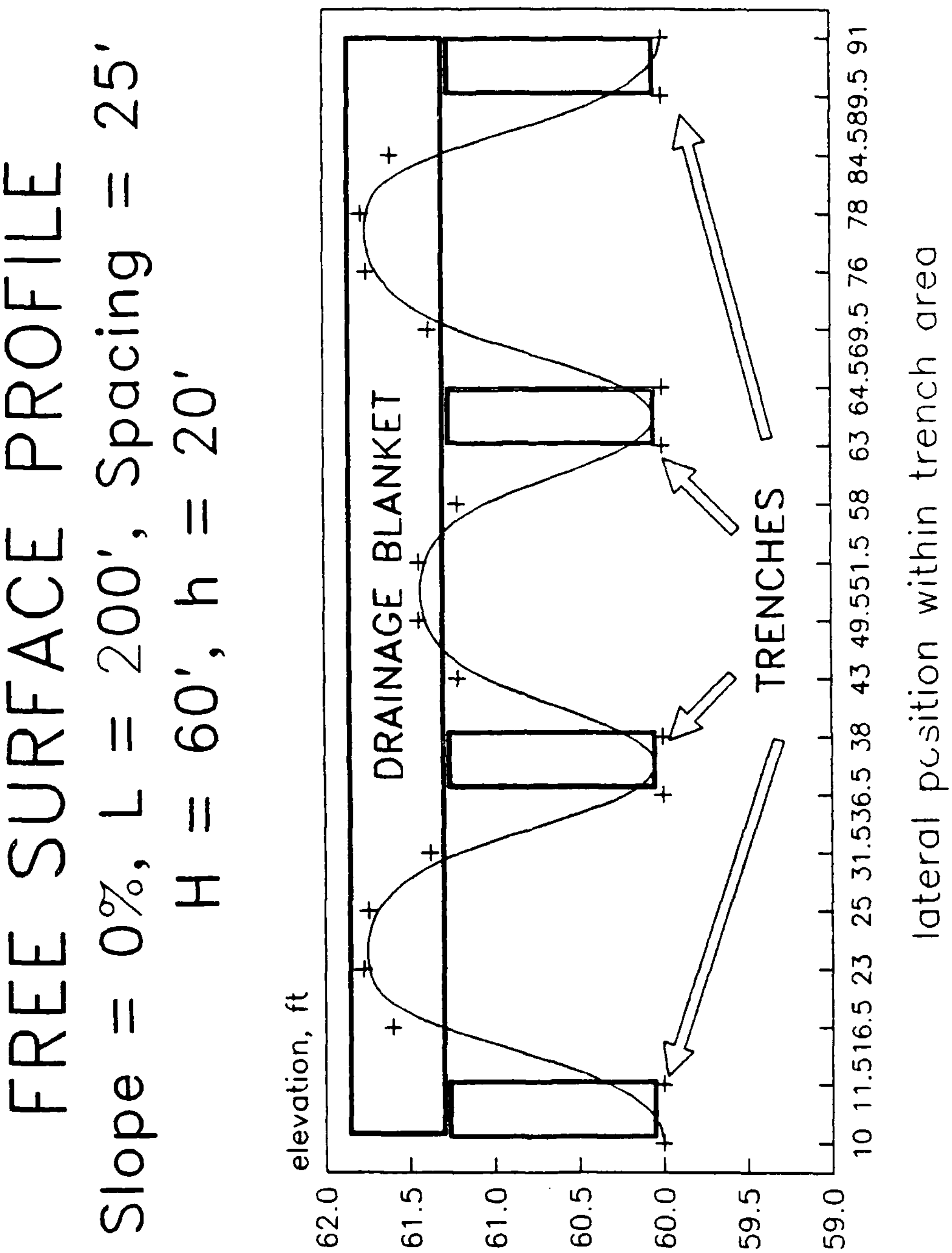

Fig. E-1
Free surface between trenches

FREE SURFACE PROFILE

Slope = 7%, L = 100', Spacing = 25'
H = 20', h = 20'

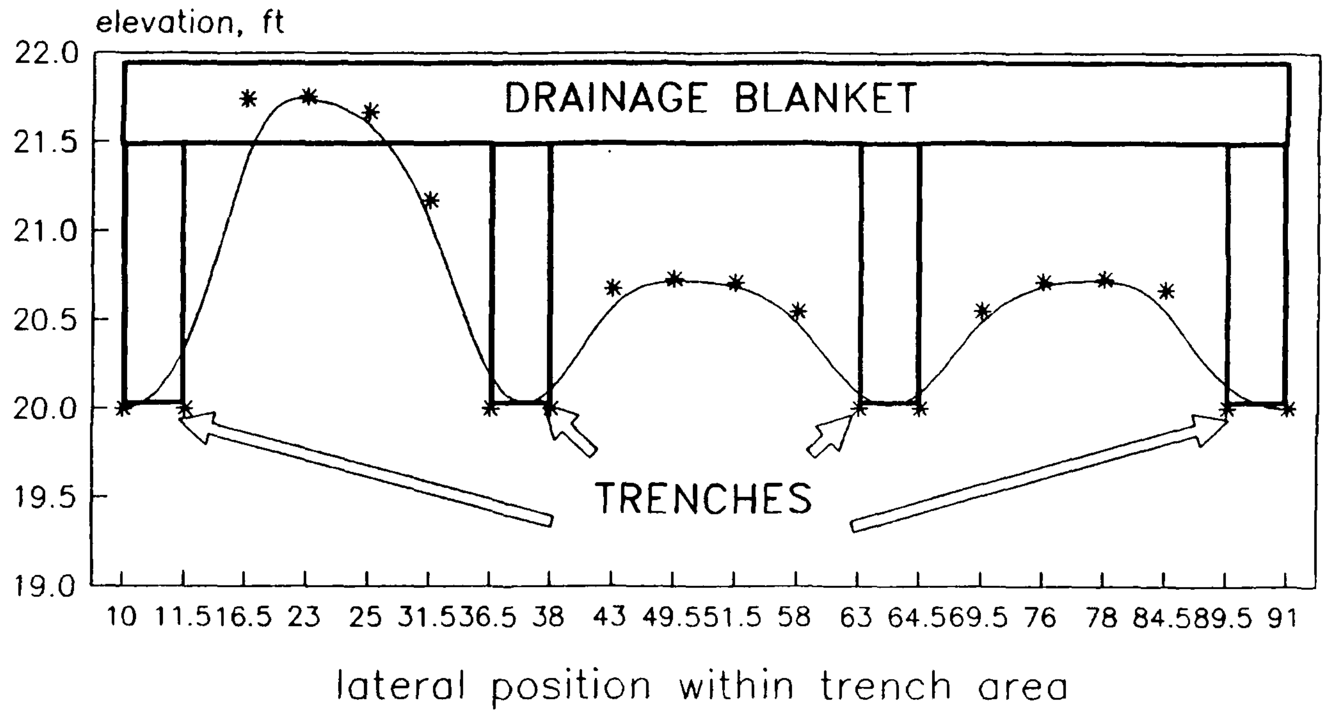

Fig. E-2
Free surface between trenches

TABLE E-2

SUMMARY OF DATA, CRITERIA B RADIUS DETERMINATION

Slope	Sp	Hr	h	Li' (ft)	q' ft^2/day	F' (ft)
0	15	20	10	325	0.12	0.26
0	25	20	10	400	0.1	0.21
0	35	20	10	500	0.09	0.16
0	15	20	20	400	0.26	0.4
0	25	20	20	375	0.23	0.46
0	35	20	20	375	0.21	0.65
0	15	60	10	400	0.19	0.44
0	25	60	10	425	0.18	0.6
0	35	60	10	400	0.18	0.7
0	15	60	20	400	0.4	0.8
0	25	60	20	375	0.39	1.05
0	35	60	20	400	0.35	1.15
3.5	15	20	10	200	0.19	0.48
3.5	25	20	10	100	0.19	0.73
3.5	35	20	10			
3.5	15	20	20	350	0.28	0.75
3.5	25	20	20	200	0.25	1.05
3.5	35	20	20	300	0.25	0.98
3.5	15	60	10	225	0.26	0.85
3.5	25	60	10	225	0.23	1.05
3.5	35	60	10	100	0.26	1.5
3.5	15	60	20	400	0.37	1.05
3.5	25	60	20	375	0.35	1.5
3.5	35	60	20	325	0.33	1.7
7	15	20	10			
7	25	20	10			
7	35	20	10			
7	15	20	20	175	0.45	1.3
7	25	20	20	150	0.47	1.5
7	35	20	20	100	0.52	2
7	15	60	10	125	0.35	1.3
7	25	60	10			
7	35	60	10			
7	15	60	20	300	0.45	1.4
7	25	60	20	225	0.49	1.95
7	35	60	20	150	0.56	3

TOTAL FLOW

(Four trench drains, 0 to 7% slope, Kv = Kh, trench width 1.5')

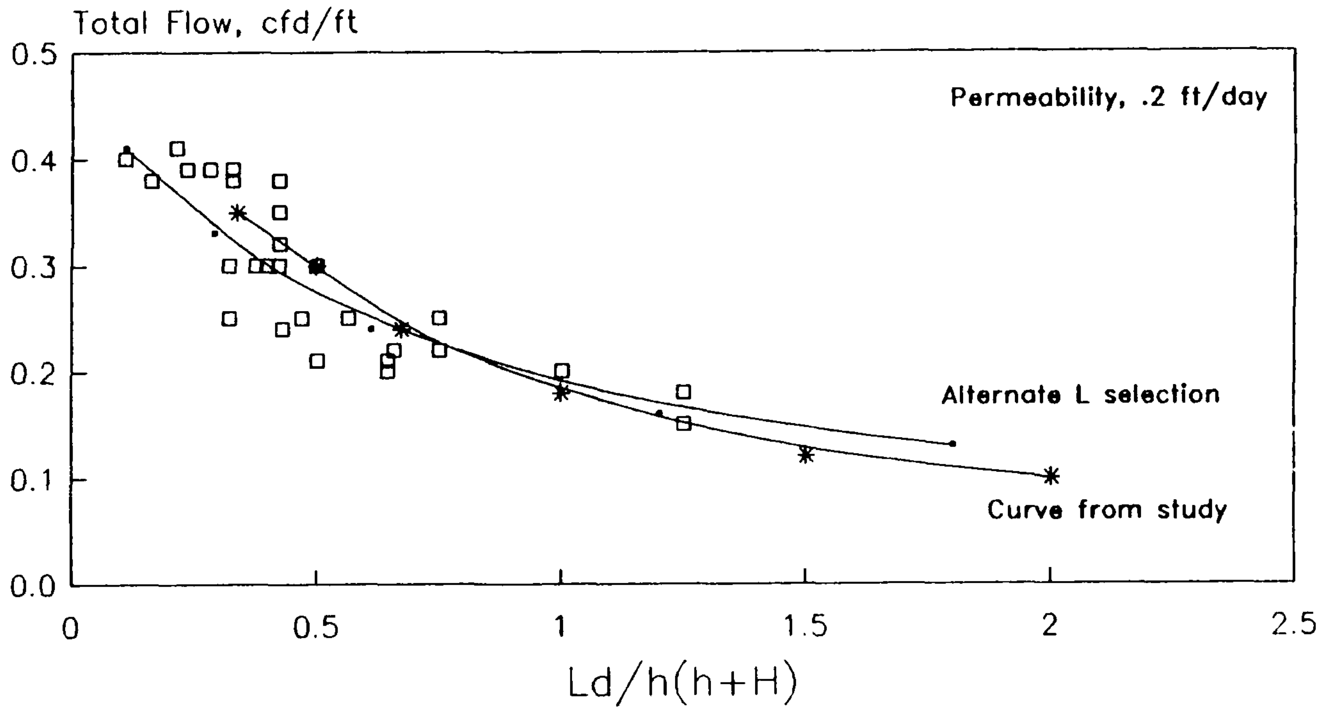

Fig. E-3
Radius selected from alternate method

Max Free Surface
(Four trench drains, Slope 0 to 7% Kv = Kh, trench width 1.5')

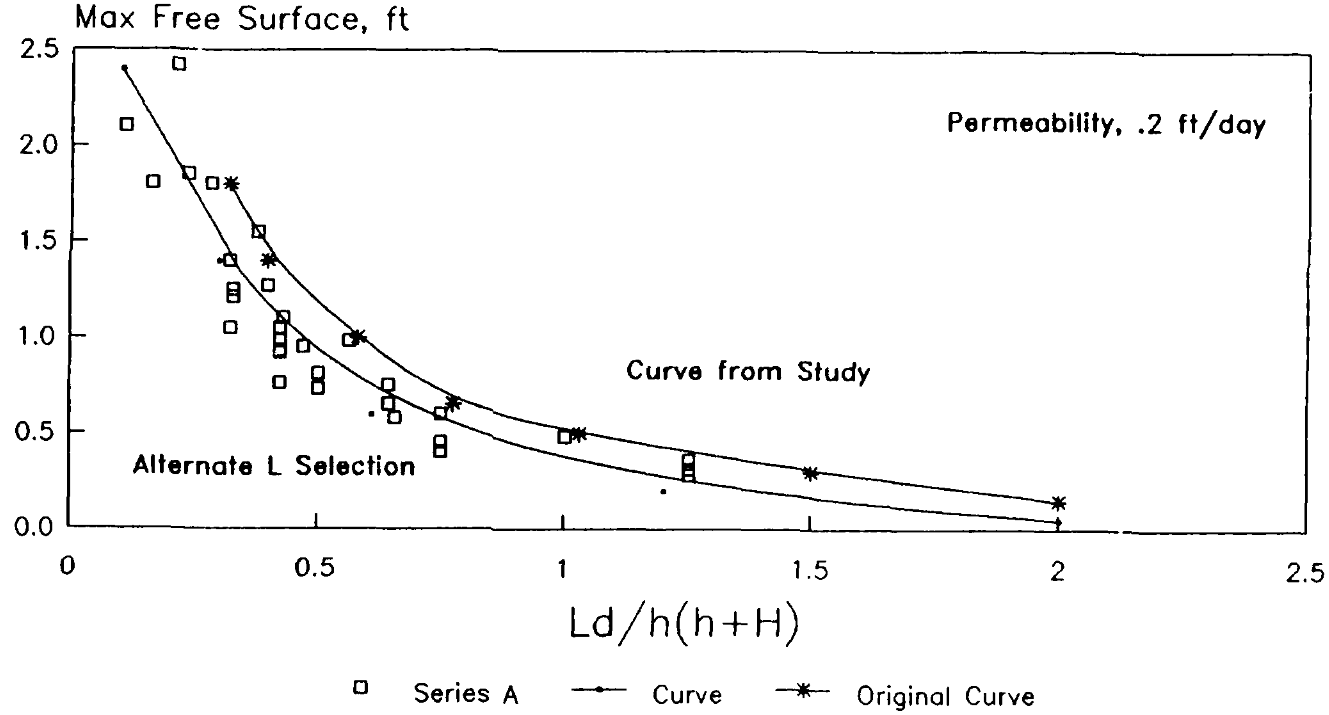

Fig. E–4
Selection of L from alternate method

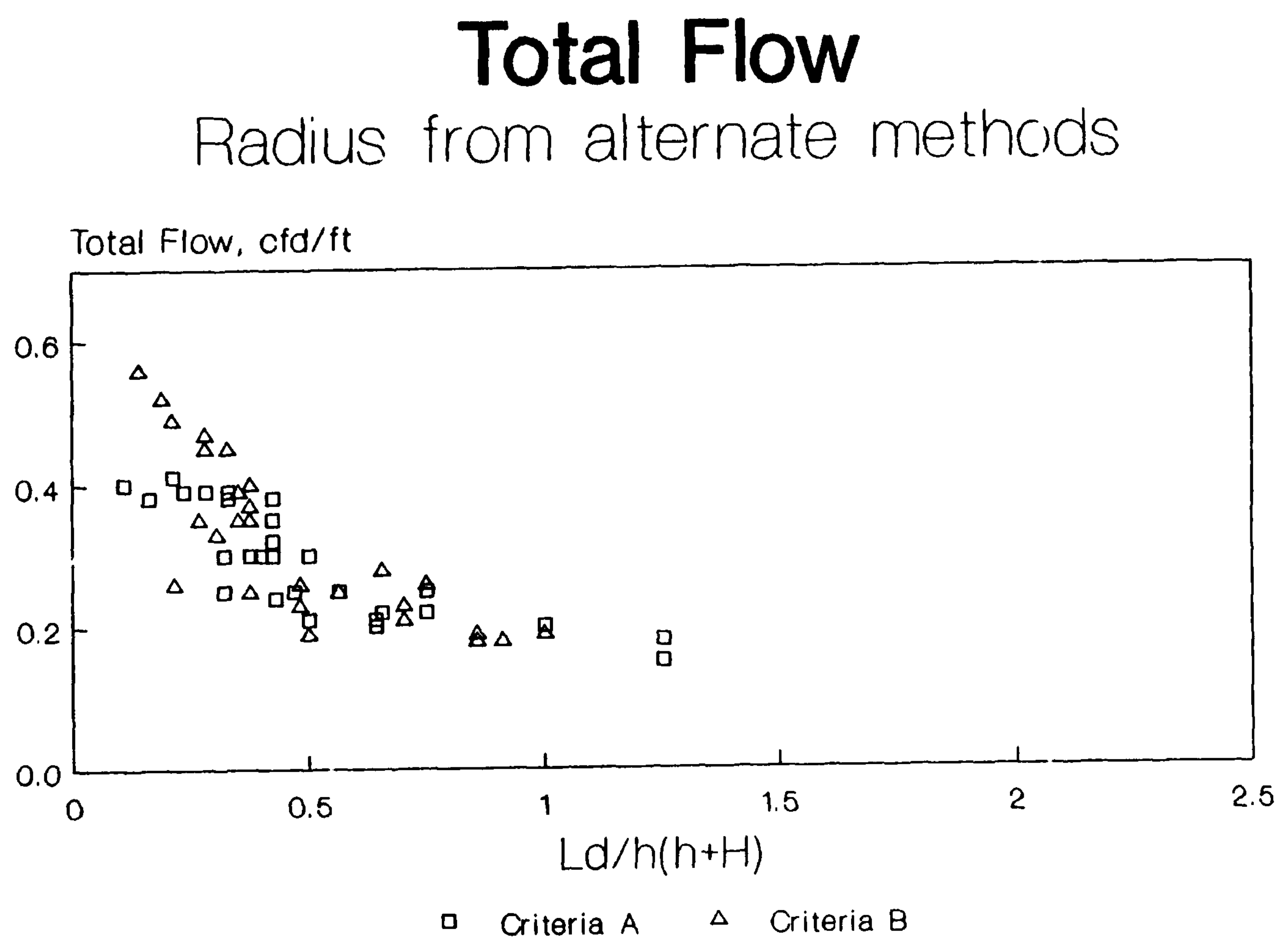

Fig E-5
Comparison of two alternate
criteria for radii determination

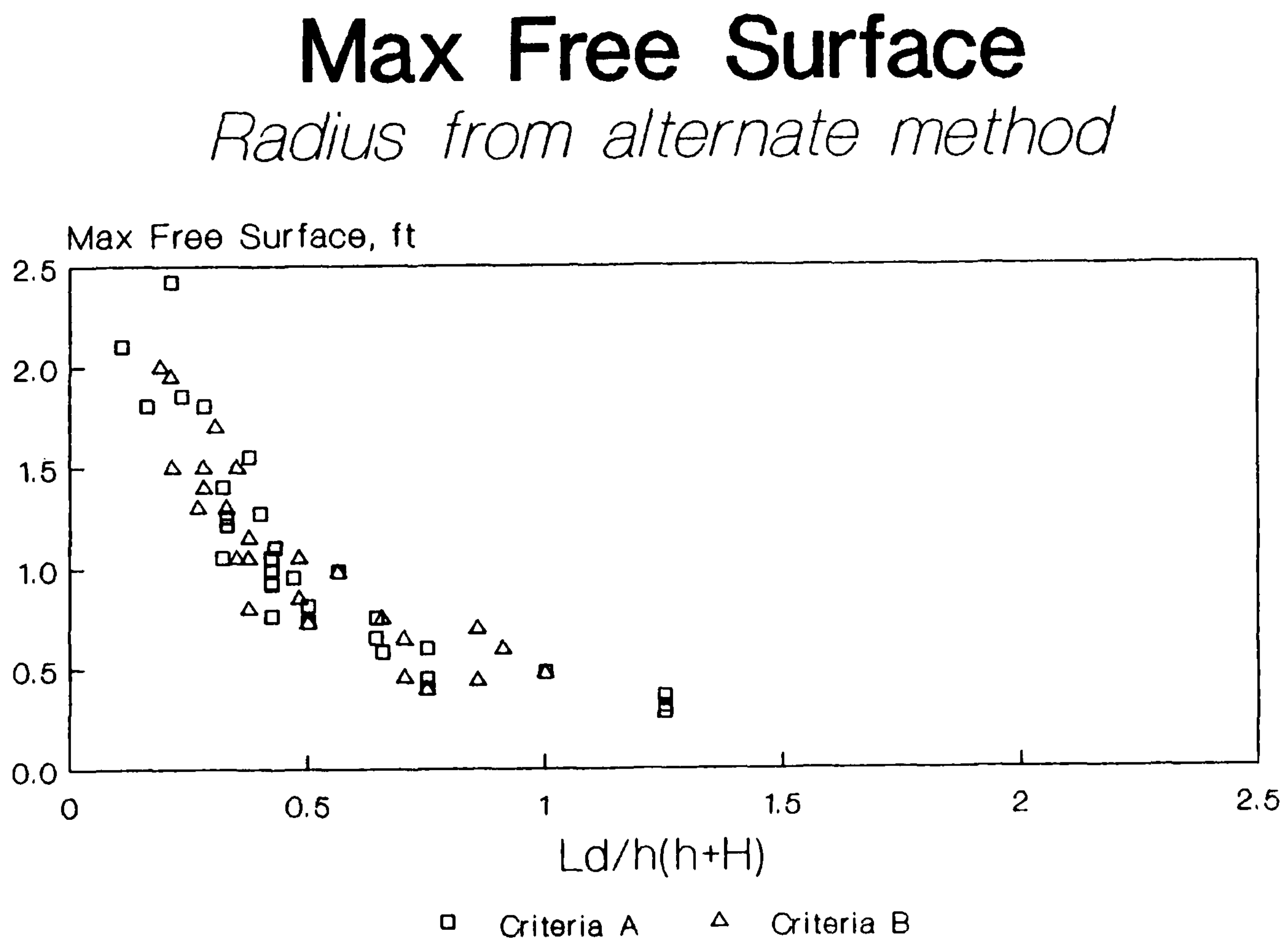

Fig. E-6
Comparison of two alternate
criteria for radii determination

Total Flow

Dimensionless Comparison from all radii determinations

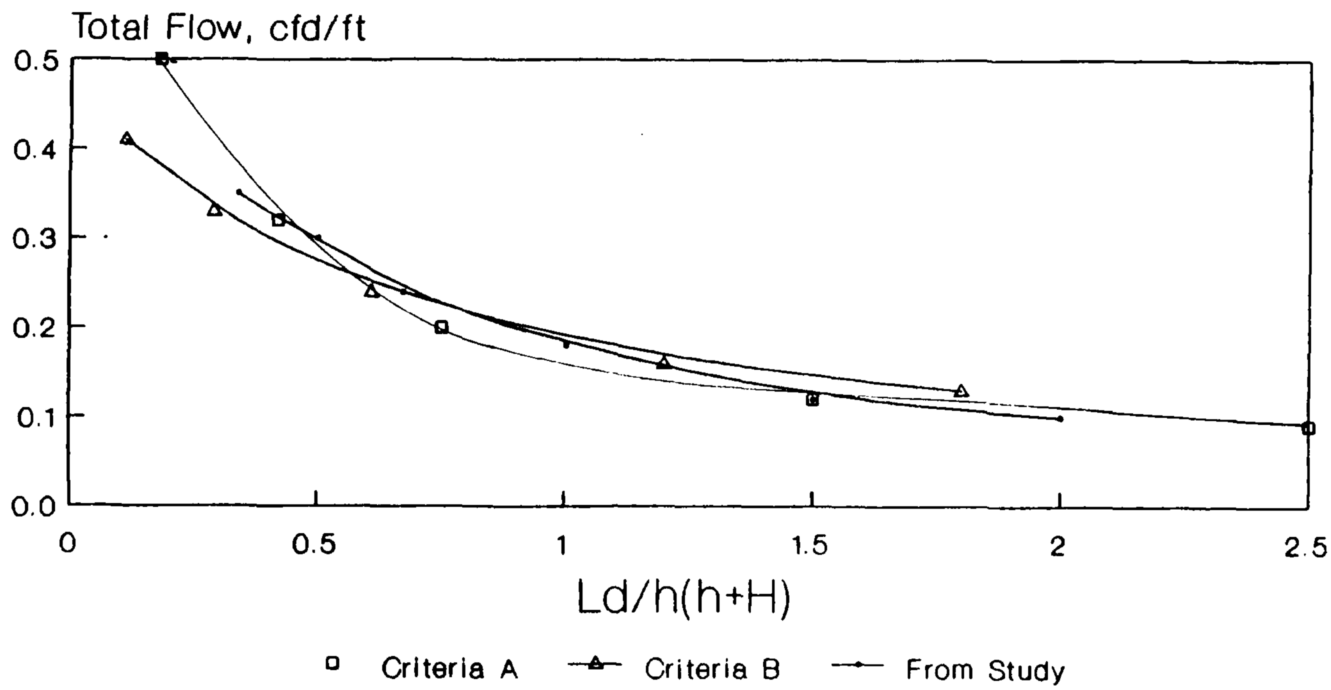

Fig. E-7
Primary and two alternate
radii determination methods

Maximum Free Surface

Dimensionless Comparison from all radii determinations

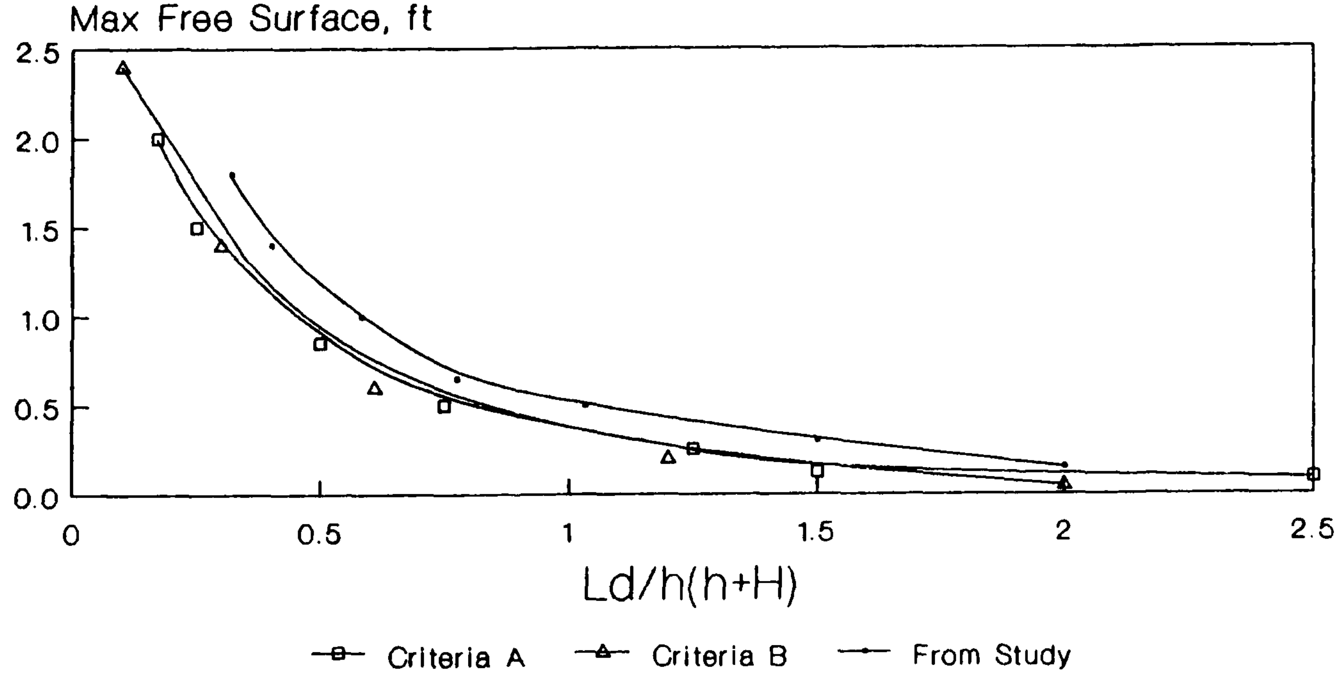

Fig. E-8
Primary and two alternate radii determination methods